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TRANSLATION

RADIATION HYGIENE
(SELECTED PARTS)

By

S. M. Gorodinskiy, G. M. Parkhomenko, et. al.

FOREIGN TECHNOLOGY DIVISION

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RADIATION HYGIENE (SELECTED PARTS)

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IONIZING RADIATION AND ITS EFFECTS ON THE HUMAN ORGANISM

Chapter 1

BASIC PROPERTIES OF RADIOACTIVE RADIATIONS*

In order to evaluate working conditions and to determine the correct approach to the development and execution of protective and prophylactic measures for work involving sources of ionizing radiation, it is necessary to have some idea of the properties and characteristics of different types of radiation.

It is now known that the smallest particles of matter are protons, neutrons, and electrons, atoms being built up from these particles. It follows from contemporary atomic theory that an atom has a diameter of approximately 10^{-8} cm. It is composed of two parts, these being the small, dense positively charged core, which is called the nucleus, and the outer, or orbital, electrons, which revolve about the nucleus in definite orbits, which form a so-called shell.

The nucleus of an atom consists of two types of particles of approximately equal mass; these are neutrons, which have no electric charge, and protons, which have a positive charge, equal in magnitude to the charge on an electron but of opposite sign. The total number of such particles in the nucleus determines its mass and is called the mass number. A total of 99.95% of the entire mass of an atom is concentrated in its nucleus.

The number of protons determines the charge on the nucleus, this being equal to the atomic number of the corresponding element in D.I.

Mendeleyev's periodic system of the elements. Electrons rotate around the atomic nucleus in definite orbitals or "shells"; in electrically neutral atoms, the number of electrons is equal to the number of protons in the nucleus. The diameter of an orbital and, consequently, the size of the atom is ten thousand times greater than the diameter of the nucleus. The number of electrons in the outer electron shell of an atom determines the chemical properties of the element. Elements which have an identical electron structure have identical chemical properties.

The electrons can shift from one orbital to another within the atom. When electrons shift from orbitals far from the nucleus to those closer to the nucleus, the atom undergoes a loss of energy, which is borne off by electromagnetic radiation. If the electron shifts occur in the peripheral section of the atom, infrared, visible, or ultraviolet light is emitted. When electrons shift to the inner energy levels, more energy is liberated and "harder" electromagnetic radiation – x-rays – is emitted.

Nuclei with the same charge but with different mass numbers are called isotopes of a given element. Nuclei with identical mass numbers but with different charges are called isobars.

The phenomenon of spontaneous nuclear reorganization was discovered by Henri Becquerel and is called radioactivity. Radioactivity is the spontaneous transmutation of atomic nuclei of the chemical elements, this process being accompanied by the emission of radioactive radiations and by a change in the physical and chemical properties of the elements.

In the majority of cases, α- or β-particles or positrons are emitted during the radioactive decay of nuclei of the atoms of elements; in the latter case, decay is often accompanied by the emission of γ-rays.

During α-decay, the atomic number of the newly formed nucleus is 2 units less than that of the original nucleus, the mass number being 4 units lower, as $Ra_{88}^{226} \xrightarrow{\alpha} Rn_{86}^{222} + He_{2}^{4}$. This type of decay is most characteristic of the radioactive elements with high atomic numbers. In β-decay, the atomic number of the newly formed nucleus is one unit greater than that of the original nucleus, while the mass number remains virtually unchanged, as $Sr_{38}^{90} \xrightarrow{\beta} Y_{39}^{90} + \beta^{-}$. This occurs as a result of the transmutation of one of the neutrons in the nucleus into a proton. This form of decay is typical of nuclei which contain an excess of neutrons and is generally accompanied by γ-radiation.

Radioactive nuclei emit uncharged particles of negligible mass, called neutrinos, simultaneously with β-particles. As a result of its small mass and zero charge, a neutrino enters into virtually no reactions with matter.

In positron decay, one of the protons of the atomic nucleus is converted into a neutron; as a result, the atomic number of the element decreases by one unit, while its atomic weight remains the same. Each emission of a positron from the nucleus is accompanied by the emission of a neutrino.

In many cases, the nuclei formed during radioactive decay have an excess of energy or, as it were, are in an excited state. When the nuclei revert to the ground state, this excess of energy is emitted in the form of γ-rays.

One of the forms of radioactive transmutation is the capture of an orbital electron by the nucleus (K-capture). In this process, the nucleus of the atom captures an electron from a shell of the same atom, the so-called K-shell of the atom. This type of decay is characteristic of nuclei which contain an excess of protons and occurs in those cases where there is not sufficient energy for the emission of a positron.

Decay results in a decrease of one unit in atomic number. This transition is accompanied by the emission of x-rays.

When radioactive substances are being used or when working with particle accelerators and other sources of ionizing radiations, it is possible for electromagnetic radiations to occur in certain cases and for corpuscular to occur in others; more precisely, these former are x-rays and γ-rays, while the latter are α- and β-particles and neutrons. Let us dwell briefly on certain characteristics of each of these types of radiation.

X-RAYS

Working with high-voltage discharge tubes, Roentgen discovered a new penetrating radiation in 1895. This type of radiation was subsequently named after its discoverer, being called roentgen rays or x-rays.

X-rays are an electromagnetic radiation with a very short wavelength (0.06 – 20A) which arises within the nucleus of an atom as a result of a loss of energy by the electrons. These rays propagate at the speed of light. x-rays can generally be produced in an x-ray tube by bombarding a metal target with electrons which have been accelerated to high energies by an electric field. In addition, they can be produced during the operation of betatrons, cyclotrons, and similar installations, in electron microscopes, in high-power transmitting tubes and rectifier tubes, and in certain electron beam tubes. Retardation x-radiation arises when free electrons in an electric field are retarded by the atomic nuclei of the matter through which they are passing.

The most important property of x-radiation is its great penetrative ability. Thus, for example, x-rays emitted at a tube voltage of 200 kv and a tube current of 10 ma (for example, in industrial radiography) can be registered at a distance of 12 m from the tube. High-en-

ergy x-rays, which are produced during the operation of contemporary betatrons can even penetrate through several centimeters of lead shielding.

X-rays have a very substantial ionizing action, this being explained principally by the secondary action of the ejected photoelectrons and electrons which they produce. Secondary radiation develops when a beam of x-rays strikes a substance; a portion of this radiation is scattered radiation. X-rays present a hazard as a factor of external irradiation. The intensity of x-radiation decreases as the distance from the source increases.

GAMMA-RAYS

According to contemporary hypotheses, γ-radiation is to be treated as a stream of photons, or energy quanta. Gamma-rays are classified as an electromagnetic radiation and have shorter wavelengths (0.001 - 0.1A) than do x-rays. When the atomic nucleus of an element emits γ-quanta, it retains the same charge and mass number.

The energy of γ-rays lies within wide limits, varying from 0.01 to 10 mega-electron volts (Mev)** or more. Depending on their energy, γ-rays can be conditionally classified as soft (with energies of up to 0.1 - 0.2 Mev), moderately hard (with energies of 0.2 - 1 Mev), hard (with energies of 1 - 10 Mev), and ultrahard (with energies of more than 10 Mev) rays. The majority of radioactive isotopes emit photons with energies of approximately 1 Mev.

The penetrating power of γ-radiation is associated with its energy. When they interact with matter, γ-rays are absorbed in accordance with an exponential rule. On passing through the human body and other low-density materials, γ-rays are subjected to a slight attenuation. Low-energy γ-rays can be attenuated by a thin layer of lead, but high-energy (hard) γ-rays can pass through a layer of lead which is several

centimeters in thickness.

The ionizing action of γ-rays is explained principally by the secondary electrons which are knocked out by the γ-quanta as they pass through a substance and which consume energy on ionization. As a result of the small extent to which γ-rays are absorbed by various materials, the ions which they form are distributed over a considerable area. The intensity of this radiation is inversely proportional to the square of the distance from the source.

Gamma-radiation presents the greatest hazard so far as external irradiation is concerned and requires the setting up of special shielding fabricated from high-density materials.

BETA-PARTICLES

Beta-particles form the stream of electrons emitted during the nuclear decay processes which occur in natural and artificial radioactive substances. The maximum energy of β-particles varies within a wide range, virtually all β-particles emitted by radioactive isotopes having energies of 3 Mev or less.

TABLE 1

Mean Free Path of β-Particles in Different Media

1 Энергия β-частиц, Мэв / 2 Среда	0,1	0,3	0,6	1,2	2,4	3,0
3 Воздух	13 см	80 см	2,2 м	5 м	11 м	14,5 м
4 Вода	0,11 мм	0,7 мм	1,7 мм	4,3 мм	9,6 мм	12,5 мм
5 Алюминий	0,046 мм	0,3 мм	0,75 мм	1,75 мм	3,8 мм	4,9 мм

1) Energy of β-particles, Mev; 2) medium; 3) air; 4) water; 5) aluminum.

The penetrating power of β-particles differs and depends on their energy; however, it is less than that of γ-rays. If the penetrating

power of γ-rays and β-particles with the same energy are compared, that of the latter will be less than that of the former by a factor of 100.

Table 1 gives data on the mean free path of β-particles of different energies in certain media.

The mean free path of β-particles in biological tissues is approximately equal to that of β-particles in water.

When passing through a substance, β-particles lose their energy as a result of various processes. These processes include resonance absorption, collision with nuclei and electrons, excitation of atoms, emission of retardation radiation, and the splitting of nuclei by electrons. For high-energy β-particles, the predominant processes are collisions, which are accompanied by the ionization and excitation of atoms, and retardation radiation; for low-energy β-particles, the principal process is ionization. Beta-particles with energies of 1 Mev can produce approximately 30,000 ion pairs along their path in air. The specific ionizing power of β-particles is several times less than that of α-particles of the same energy and substantially greater than that of γ-rays.

Beta-particles can act on an organism either by external irradiation, which injures the skin and mucous membranes, or by internal irradiation, when β-radiators get into the organism. Protection from external irradiation with β-particles is achieved by the use of special shielding or by increasing the distance from the source of radiation.

A β-particle which has a positive charge is called a positron. The positron is a particle which is formed when certain artificial radioactive isotopes (such as Na^{22}) decay. When it interacts with matter, a positron combines with an electron, this resulting in the emission of a γ-quantum. The properties of positron radiation are similar to those

of ordinary β-radiation, but positrons are diffracted in the opposite direction from electrons in magnetic and electric fields.

ALPHA-PARTICLES

Alpha-particles are the nuclei of helium atoms, having a double positive charge and a mass of 4. One α-particle is approximately equiv-

TABLE 2

Penetrating Power and Ionization Density of Radiation of Various Types with Energies of 2 Mev

1 Тип излучения	2 Длина пробега в воздухе, м	3 Плотность ионизации, число пар ионов на 1 мм
4 Альфа-частица	0,01	6000
5 Бета-частица	10	6
6 Гамма-квант	600	0,1

1) Type of radiation; 2) mean path in air, m; 3) ionization density, number of ion pairs per mm; 4) alpha-particles; 5) beta-particles; 6) gamma-quantum.

alent to 7,000 electron masses. Alpha-particles are ejected from the nucleus of an atom at a velocity of approximately 14,000 – 20,000 km/hr. These particles have energies of the order of 2 – 9 Mev.

Alpha-radiation is observed principally in the naturally radioactive elements (radium, thorium, uranium, polonium, et al.). Alpha-particles propagate in almost straight lines in all media, setting up a high-density ionization along their path. The physical properties of α-particles determine the characteristics of their biological effects on an organism and the methods of protecting against this kind of radiation.

Alpha-particles have a short mean path in air, water, and other materials. The length of the path is determined by the energy of the α-particles. Their paths are 2 – 9 cm in air and 0.02 – 0.06 mm in water and biological tissues. An 8 – 10 cm layer of air, a sheet of tissue paper, or a thin layer of aluminum is sufficient to absorb α-particles.

One of the most important properties of α-radiation is its high ionization density. Alpha-particles are biologically more effective than an x- or γ-rays or β-particles.

Table 2 shows comparative data on the ionization densities of different types of radiation of identical energy (2 Mev) which generate an equal number of ion pairs along their paths.

The ionization density of an α-particle increases at the end of its path and the injury to a cell at the end of its path is consequently greater than that to a cell traversed at the beginning of its path by a factor of approximately 2.

Alpha-radiators present no danger as a source of external irradiation. It is sufficient to remove a source of α-radiation to a distance of 10 – 20 cm from a human being or to place a very simple screen fabricated from paper, aluminum, glass, or other materials in front of him in order to absorb the radiation.

The basic danger inherent in α-radiators lies in their getting into and being deposited within an organism. In such cases, direct contact occurs and the α-particles act directly on the cells and tissues of the organism.

Protons, just as α-particles, are heavy particles and interact with matter in a similar fashion, generating a high-density ionization within it.

NEUTRONS

Neutrons are particles which have no electric charge. They decay into a proton and an electron within a period of approximately 10 – 30 minutes. The mass of a neutron is approximately equal to the mass of a proton. Because neutrons are uncharged particles, a substance through which they pass is not ionized in a direct fashion. Depending on their kinetic energy, neutrons can be approximately classified into

fast (with energies of 0.5 – 10 Mev), ultrafast (with energies of 500 Mev or more), intermediate (from 5 kev to 0.5 Mev), slow (with energies of approximately 0.1 ev), and thermal (with energies of approximately 0.025 ev) neutrons.

Neutron radiation has a high penetrating power. In contrast to γ-rays, neutrons are more easily slowed down by low-density substances than by high-density elements. When fast neutrons interact with the nuclei of atoms, they transfer their energy to these nuclei and are slowed down. A stream of fast neutrons is halved by the time it reaches a depth of 4 – 6 cm in an organism. At this depth, approximately half of the fast neutrons have been converted into slow neutrons (M. I. Shal'nov). On colliding with atoms, slow and thermal neutrons enter into nuclear reactions with them, this resulting in the emission of ionizing radiation. In this case, stable or radioactive isotopes are formed.

When fast neutrons collide with hydrogen nuclei (protons), the neutrons transfer a certain portion of their energy to the nuclei and these in turn cause ionization in the tissues; atoms of heavy hydrogen are formed and γ-rays are emitted.

Slow neutrons are ultimately absorbed by the nuclei of the atoms, generally hydrogen or oxygen, in the tissues of the organism.

Alpha- or beta-particles may be produced as a result of the interaction of the neutrons with the nuclei of elements.

The principal sources of neutrons are nuclear reactors and cyclotrons. In addition, neutrons are emitted in mixtures of such elements as radium and beryllium or polonium and beryllium.

External irradiation of personnel is possible when working with neutron sources. Taking into account the particular properties of neutron radiation, it is necessary to provide shielding for the reactor

chamber which is made from materials which contain a considerable percentage of hydrogen, boron, or special metals (cadmium et al.).

UNITS OF RADIOACTIVITY

Every radioactive atom decays and is converted into another stable or radioactive atom.

A radioactive element can decay over a brief period of time, a second or a fraction of a second, or over a longer time (days or years). The greater the number of decays which occur per unit time, the greater will be the activity of the substance.

It is customary to use the length of the halflife (T) of an element as an index of the rate of radioactive decay. The halflife is that time interval over which the activity of the radioactive element decreases by half. The rate of radioactive decay is constant for each element and is independent of the physical and chemical properties of the isotope. It does not vary with changes in temperature, pressure, chemical state, or under the action of any physical factors whatsoever.

In working out improved prophylactic measures and evaluating working conditions for work involving the handling of radioactive elements, it is necessary to take into account the halflife of the isotope.

For example, when working with shortlived radioactive isotopes (T = several minutes), it is not necessary to use special cleansing methods if work clothes or equipment are contaminated, since the initial contamination decreases extremely rapidly or disappears entirely as a result of decay. This is also true of wastes, whose activity decreases rapidly as time goes on.

The quantity of radioactive matter is determined not by its weight, but by its activity. The activity of a radioactive element is a measure of its quantity, expressed as the number of nuclear decays per unit time. The curie is used as the unit for measuring activity.

The curie is the activity of a preparation of any radioactive element in which $3.7 \cdot 10^{10}$ acts of decay per second occur. It is often necessary in practice to convert the value of the curie into decays per minute, it thus being necessary to make the computation that 1 curie = $3.7 \cdot 10^{10}$ acts of decay per second or $2.22 \cdot 10^{12}$ decays per minute.

The millicurie (1 millicurie = 10^{-3} curie and corresponds to $3.7 \cdot 10^{7}$ decays per second) and microcurie (1 microcurie = $1 \cdot 10^{-6}$ curie = 10^{-3} millicurie and corresponds to $3.7 \cdot 10^{4}$ decays per second) are derived from the curie.

There is a definite relationship between the weights of radioactive substances and their activity, this relationship being expressed by the following ratios shown in Table 3.

TABLE 3

Conversion Coefficients Relating Weight of Preparation and Its Activity

1 Вес препарата, г/к (без неактивного носителя)	2 Активность, соответствующая 1 г радиоактивного препарата, к/г	3 Если период полураспада выражен
$8.9 \cdot 10^{-14}$ AT*	$\frac{1.13 \cdot 10^{13}}{AT}$	4 В секундах
$5.3 \cdot 10^{-12}$ AT	$\frac{1.88 \cdot 10^{11}}{AT}$	5 В минутах
$3.2 \cdot 10^{-10}$ AT	$\frac{3.10 \cdot 10^{9}}{AT}$	6 В часах
$7.7 \cdot 10^{-9}$ AT	$\frac{1.30 \cdot 10^{8}}{AT}$	7 В днях
$2.8 \cdot 10^{-6}$ AT	$\frac{3.57 \cdot 10^{5}}{AT}$	8 В годах

1) Weight of preparation, g/curie (without inactive carrier); 2) activity of 1 g of radioactive preparation, curies/g; 3) if halflife is expressed; 4) in seconds; 5) in minutes; 6) in hours; 7) in days; 8) in years.

*1A designates the atomic weight and T designates the halflife. For example, the weight (Q) of 1 curie of P^{32} (A = 32, T = 14.3 days) will be: $Q = 7.7 \cdot 10^{-9} \cdot 32 \cdot 14.3 = 3.52 \cdot 10^{-3}$ mg = 3.52 μg (M.G. Gusov, 1956).

The rutherford (rd) is frequently used abroad for expressing activity. The rutherford is the activity of a quantity of radioactive substance in which 10^6 decays occur per second. The curie and the rutherford are generally used to characterize the α- or β-activity of radioactive substances.

The concentration of radioactive substances in liquids or gaseous media is expressed in curies per liter.

Gamma-activity is expressed in milligram-equivalents of radium. A milligram-equivalent of radium is the activity of any radioactive preparation whose gamma-radiation under identical measurement conditions causes the same ionization in an air-equivalent ionization chamber as does 1 mg of radium which meets the State Standard of the U.S.S.R. for radium, when a 0.5 mm platinum filter is used.

1 milligram-equivalent of radium corresponds to the γ-activity of any radioactive substance for which a point source sets up a physical dose with a power of 8.4 r/hr at a distance of 1 cm.

The roentgen is used as the unit of x- or γ-ray dosage. The roentgen is the dose of x- or γ-radiation in air with which the combined corpuscular emission per 0.001293 g of air produces ions in the air which carry a charge of 1 electrostatic unit of each sign. The number 0.001293 is the mass in grams of 1 cm^3 of atmospheric air at a temperature of 0° and a pressure of 760 mm Hg. One roentgen (r) is equal to 10^3 milliroentgens (mr) or 10^6 microroentgens (μr).

The dose delivered per unit time is called the power of the physical dose. The relationship between dose power units is as follows:

1 r/hr = 10^3 mr/hr = 10^6 μr/hr.

1 r/hr = 16.7 mr/min = 16,700 μr/min.

1 r/hr = 0.28 mr/sec = 280 μr/sec.

1 μr/sec = 60 μr/min = 3,600 μr/hr.

1 μr/sec = 0.06 mr/min = 3.6 mr/hr.

1 μr/sec = $6 \cdot 10^{-5}$ r/min = $3.6 \cdot 10^{-3}$ r/hr.

The following relationship exists between the physical dose power P (in microroentgens per second) and the γ-activity m of a point source, expressed in milligram-equivalents of radium:

$$P = \frac{m \cdot 8.4 \cdot 10^4}{R^2 \cdot 3600} = 2300 \frac{m}{R^2}$$

where R is the distance from the source, expressed in centimeters. If R is expressed in meters and m is expressed in milligram-equivalents of radium, $P = 0.23\ m/R^2$ μr/sec.

The physical dose of corpuscular radiation (α- and β-particles, protons, recoil nuclei, et al.) is represented by the physical equivalent of a roentgen (fer). A physical equivalent of a roentgen is that dose of any ionizing radiation with which the energy absorbed per gram of matter is equal to the energy loss in ionization generated by a dose of 1 r of x- or γ-rays in 1 g of air. A dose of 1 fer corresponds to the formation of $20.8 \cdot 10^9$ ion pairs in 0.001293 g of air.

1 fer = 84 erg/g = $1.61 \cdot 10^{12}$ ion pairs/g = $5.3 \cdot 10^7$ Mev/g.

When a biological tissue is irradiated with a 1 r physical dose of γ-rays, each gram of tissue absorbs approximately 93 ergs of the energy of the radiation.

In 1953, the Seventh International Congress of Radiologists recommended that a new unit of energy absorption, the rad, be used instead of the fer. This unit has also been adopted in the Soviet Union. The rad corresponds to an absorbed energy of 100 ergs in 1 g of any substance, this energy being supplied by any ionizing radiation:

1 fer = 0.84 rad and 1 rad = 1.19 fer.

Chapter 2

BIOLOGICAL EFFECTS OF IONIZING RADIATION

A characteristic property of the action of radiant energy is its ability to cause the ionization of atoms and molecules. In this case, charged particles (α- and β-particles, protons, etc.) ionize directly the atoms of the medium through which they pass; electrically neutral radiation (x- and γ-rays, neutrons) ionize the atoms of the medium through which they pass by means of secondary processes. Ionizing capacity is a function of the magnitude of the energy possessed by a certain type of radiation. It has been established that an energy of the order of 32.5 ev is necessary to produce one ion pair in air (at a temperature of 0° and a pressure of 760 mm Hg), while 35 ev are required to produce an ion pair in the soft tissues of the human body. Sources of ionizing radiation may be found either inside or outside the organism; in the latter case, we speak of incorporated radioactive substances. However, in addition to the number of ions generated by a certain type of radiation, its mass, charge, and physical nature also play a role in determining the characteristics of its biological effect.

The primary mechanisms of the biological effects of different types of radiation are very similar and, in a number of cases, are even identical. The differences in the nature of these effects are determined by the degree of penetration, the specific ionization, the irradiation dose, the time for which the radiation acts, and the condition of the organism.

According to contemporary theories, ionization of the atoms and

molecules of living matter is the first phase in the biological effect of radiation.

The most characteristic property of all types of penetrating radiations is their ability to knock electrons out of the electron shells of the irradiated substances and thus cause them to ionize. The loss of a negatively charged particle (electron) produces a positively charged atom or molecule. The knocked-out electron, attaching itself to another molecule, converts the latter into a positively charged ion. For example, the ionization of neutral water molecules and the formation of one ion pair can thus be represented in the form $H_2O - e^- = H_2O^+$; $H_2O + e^- = H_2O^-$.

The effects of x- and γ-rays result from the appearance of secondary electrons, which are formed when x- or γ-quanta are absorbed or scattered. The ionization which occurs under the action of fast neutrons is a result of the recoil protons which are formed when the neutrons collide with the nuclei of hydrogen atoms. The effects of slow neutrons result from the ionizing action of the particles which are formed in the nuclear reactions caused by these neutrons. Radioactive substances are formed in the organism under the influence of neutrons; this produces so-called induced radioactivity. The ionization produced by induced radioactivity is approximately 1% of the total ionization caused by other types of neutron irradiation (with recoil protons).

Atoms acquire a considerable activity as a result of ionization. This activity causes changes which may have an unfavorable effect on the cells and tissues of the organism. The lethal x-ray dose for man (500 r) produces approximately 10^6 ionized atoms in a cell, out of a total number of atoms of the order of 10^{14}, i.e., approximately 1 ionized atom for each 10,000,000 nonionized atoms.

Under certain conditions, the ionization of a molecule of water and the reactions associated with this process cause the formation of radicals, which can react with any substance capable of being oxidized or reduced. The most important of these radicals are atomic hydrogen (H), the hydroxyl (OH) and hydroperoxyl (HO_2) ions, and hydrogen peroxide (H_2O_2).

Short-lived free radicals cause the development of chemical chain reactions, the nature of which has not as yet been sufficiently well studied. According to Barron's theory*, free radicals interact with the most active structures of ferment systems, sulfhydryl groups (SH), and convert them into inactive disulfide groups (S = S). For example, the oxidation of the sulfhydryl groups of protein molecules may be represented in the following form (according to Barron):

$$2R-SH+2OH=R-S-SR-+2H_2O;$$
$$2R-SH+2O_2H=R-S-SR-+2H_2O_2;$$
$$2R-SH+2H_2O_2=R-S-SR-+2H_2O.$$

Such oxidation causes a disruption of the catalytic activity of the extremely important thiolic ferment systems, which take part principally in the synthesis of nucleoproteids and nucleic acids.

P.D. Gorizontov (1958) has shown that the hypothesis that free radicals take part in the biological effects of ionizing radiations is indirectly confirmed by such phenomena as the increase in the resistance of the organism to the action of radiation when the partial oxygen pressure is reduced and under conditions which lead to hypoxia in the organism, the possibility of radical formation then being greatly reduced. The experiments conducted by Daudi (Dowdy, 1950) showed that irradiation of mice or rats in an atmosphere containing 5-7% oxygen leads to a sharp increase in percentage survival, even when absolutely lethal doses are used.

Since the ways in which short-lived (fractions of a second) free

radicals cause prolonged radiochemical processes are still not clear, B.N. Tarusov has advanced a new concept of the development of self-accelerating chain reactions. He presented the hypothesis that a chain reaction develops in the irradiated fats, this reaction proceeding through a series of intermediate products and leading to an accumulation of toxins of a lipoid nature. This viewpoint is confirmed by a number of investigations of the formation of biologically active products in the organs and tissues of animals subjected to the action of ionizing radiation. Despite the fact that, in the opinion of many scientists, radiochemical processes occurring in water are not the only mechanism by which ionizing radiation affects living biological structures, the theory of a direct effect through the products formed in the radiolysis of water still remains a relatively basic concept of the primary biological action of ionizing radiation.

In order to understand the pathogenesis of radiation sickness, it is also necessary to take into account reactions more complex than the direct action of ionizing radiation on tissue. These reactions are based on the mechanisms which govern the interaction of the organism and its environment. In addition to the possibility that ionizing radiation has a direct detrimental effect on tissue and the humoral environment, it is necessary to take into account the possibility that ionizing radiation has an indirect effect on the organism, by way of its nervous system.

The work of Soviet investigators (P.D. Gorizontov, A.B. Lebedinskiy, M.N. Livanov, Ye.I. Bakin, et al.) gives us a basis for assuming that it is possible for ionizing radiations to have a direct detrimental effect on tissue, for the toxic products formed in damaged tissues to exert humoral influences on the organism, and for dystropic disturbances mediated by the nervous system to develop.

The biological effect, i.e., the reaction of the organism to the influence of ionizing radiation, depends on the irradiation dose, the type of radiation, the quantity of energy absorbed by the organism, the time for which the radiation acts, the size of the irradiated area, and individual radiosensitivity. It has been established that, for equal quantities of absorbed energy (expressed in units such as the rep), different types of radiant energy have different biological effects. As a result, the coefficients of relative biological effect (RBE) have been established.

For identical quantities of absorbed energy, α-rays produce a biological effect which is more intense by a factor of 10 than that produced by γ- and x-rays, while fast neutrons of different energies produce an effect more intense than that of the latter by a factor of 10-20. It is necessary to emphasize that the RBE factor is conditional, since the characteristic selected for comparing the biological effects is of great importance. These factors may be determined from the percentage mortality, the extent of hematological changes, etc., and accordingly differ in significance. Relative biological effect factors are often used for evaluating the results of the combined action of several types of radiation and for determining the total dosage, which is expressed in terms of the conventional roentgen equivalent biological.

The roentgen equivalent biological is the quantity of energy of any type of radiation absorbed in biological tissue whose biological effect is equivalent to that of 1 r of x- or γ-rays (this unit is abbreviated reb). The reb differs for different types of radiation.

In many respects, the difference in biological effect depends on the type of radiation and the ionization density produced in the

tissues, i.e., on the "specific ionization." This term is used to refer to the number of ion pairs produced in a substance along a unit ionizing radiation path (linear) or in a unit volume of the substance (volumetric). In this case, the ionization density decreases as the penetrating power and mean free path of a particle increase. Alpha-particles have the lowest penetrating power and they consequently generate a high ionization density in small areas, causing substantial changes in various tissues. In many respects, this phenomenon explains the characteristics of the action of certain types of radiation.

The linear ionization density in turn depends on the form and nature of the radiation involved. Consequently, the same quantity of energy absorbed from different types of radiation can cause different biological effects. These characteristics of the effects of ionizing radiation on the living cell are illustrated in Fig. 1, where it is shown that the relative biological effect caused by a given quantity of absorbed energy varies markedly with a change in the density of ion formation along an ionizing particle path.

Irradiation time, this including both duration and fractionation, is an important factor in the biological effect of radiation. The biological effect increases as the irradiated surface and body areas increase.

In many respects, the biological effect of ionizing radiations depends on the individual radiosensitivity of the organism in question. The characteristics of an organism manifest themselves to the greatest degree during irradiation in small doses. The sensitivity of young people, especially children, to irradiation is greater than that of the middle-aged.

Despite the fact that the general mechanisms of the biological effect of any mode of irradiation are the same, internal irradiation

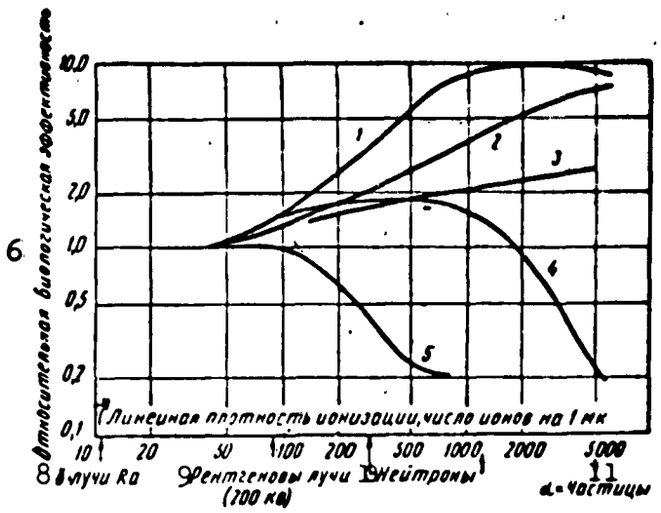

Fig. 1. Change in relative biological effect (RBE) as a function of linear ionization density for several types of radiobiological effects. 1) Suppression of growth (tumors in mice, wheat sprouts, broad beans); 2) isochromatid breaks (spidewort); 3) chromatid breaks (spidewort); 4) suppression of mitosis (broad beans); 5) inactivation of tobacco mosaic virus; 6) relative biological effect; 7) linear ionization density, number of ions per micron; 8) γ-rays, Ra; 9) x-rays (200 kv); 10) neutrons; 11) α-particles.

has its own characteristic properties. Damage caused by irradiation from internal sources can manifest itself when radioactive substances in the form of gases, vapors, or aerosols enter the organism during inhalation or ingestion or through wounds, which may or may not break the skin.

The inhalation or ingestion of β- or α-active substances can cause tissue damage, the nature of which depends on the organ in which the substance in question accumulates. Radioactive substances behave in different ways within an organism and vary in radiotoxicity in accordance with the manner in which they are absorbed, their chemical nature and properties, their solubility, the dispersion of

aerosol particles, the manner in which they are expelled from the organism, the effective half-life, half-life and quantity of the substances in question, etc.

The characteristics of the toxicological effect of radioactive substances include high biological activity despite extremely low weight (for example, 1 millicurie of polonium weighs $2.4 \cdot 10^{-10}$ g), the absence of any possibility of neutralization, specificity of clinical appearance and course, and a number of other factors.

When radioactive substances enter an organism, their distribution and expulsion are determined by their physical and chemical properties, as well as by the functional state of the organism. Individual radioactive elements are observed to accumulate primarily in certain tissues and organs. For example, radioactive iodine (I^{131}) accumulates principally in the thyroid gland, radon (Ra^{226}), strontium ($Sr^{89,90}$), and a number of other elements accumulate in the bones, and niobium (Nb^{95}), sodium (Na^{24}), and other elements are distributed more or less uniformly throughout the organism. Certain characteristics of the distribution of radioactive substances are not always constant. We can frequently observe a redistribution of elements over a period of time, this depending on the physical and chemical properties of the elements, the functional state of the organism, and other factors. As a result of redistribution, certain substances which had originally settled in a region such as the lungs can gradually pass into the bony tissue, the liver, etc.

D.I. Zakutinskiy believes that the quantity of a radioactive element which accumulates in a given organ does not of itself completely determine the development of pathological changes in that organ alone. Recent data show that, even when a small quantity of radioactive substances accumulates in the central nervous system, its

functional state changes substantially. Disruptions of the functional state of the central nervous system have a material influence on the absorption of radioactive substances, their distribution within the organism, and the course of radiation sickness. However, the preferential accumulation of radioactive substances in certain organs determines the development of severe pathological processes such as malignant growths and other changes within these organs at definite times after irradiation.

Radioactive substances are excreted from the organism through the gastrointestinal tract, the kidneys, and, for those substances in a gaseous state (radon, thoron, etc.), the respiratory organs. Certain of these substances may be excreted by the mucous lining of the mouth, the skin, and the mammary glands. The greatest quantity of radioactive substances is excreted during the first few days after they enter the organism, but many elements (such as thorium, radium, strontium, etc.) are excreted slowly, remaining in the organism for a long period of time. The term "effective half-life" is used in speaking of the time necessary to excrete radioactive substances. This half-life is the time necessary for the organism to dispose of half of the radioactive substance which it contains. In speaking of the effective half-life of short-lived elements, we take into account both the quantity of substance which the organism has been able to excrete and the quantity which has decayed. When dealing with a substance having a long half-life, it is practical to take into account only that quantity of the substance which the organism excretes. At the present time, the relationship between the content of an element in the body and the amount of this element expelled from the organism has been more or less accurately established only for certain substances such as radium, uranium, etc. (V.A. Sanotskiy).

However, it is not always possible to evaluate the actual accumulation of radioactive substances in the organism or the degree of injury from the amount of these substances excreted in the urine and feces. At certain times after irradiation, the organism may be a carrier of radioactive substances, but these can be detected in its secretions only occasionally or not at all. The elements which are most easily removed from the organism are those which form easily soluble salts and are uniformly distributed throughout the organism (for example, radioactive sodium, etc.).

Once radioactive substances are deposited within the organism, it is extremely difficult to increase the natural rate at which they are excreted. The many drugs suggested for this purpose have not always had the requisite effect.

The most dangerous radioactive substances to have enter the organism are those which emit α-particles, since these have a high specific ionization; β-radiators are also quite dangerous. In tissue, α-particles produce 1 ion pair after they have traversed a path of 10^{-8} cm, while β-particles have the same effect when they have traversed a path of 10^{-5} cm. Since the diameter of a water molecule is approximately 10^{-8} cm, all water molecules located on the path of an α-particle (several microns) will thus be ionized. A β-particle can ionize only one molecule out of each 1000 which lie on its path (several millimeters). The damage caused to cells by ionizations produced by α-particles will consequently be concentrated in a small area, while that caused by β-particles will be more widely dispersed.

The conditions under which ionizing radiation may act on man are extremely diverse in nature. Such exposure may occur when working with x-ray apparatus, during radiography, radioscopy, or x-ray structural analysis, when working with the different types of γ-ray appara-

tus used in industry and medicine, when handling radioactive substances, or when working with unshielded isotopes, during suspension, unpacking, or solution. Such exposure is also possible during the operation of reactors, accelerators, and various types of power installations, while mining and processing radioactive ores, in the production of radioactive isotopes, etc.

It is also possible for exposure to ionizing radiation to affect the health of individuals in those cases where proper radiation safety precautions are violated in the course of work and conditions are set up whereby the personnel involved may be overexposed.

The development of a pathological process in the organism can manifest itself through different clinical syndromes of radiation sickness, depending on the physical and chemical properties of the radioactive substance, its half-life, quantity, and penetrative path in the organism, the extent to which it is absorbed, and the radiosensitivity of the individual in question.

Radiation sickness may be characterized as acute or chronic, depending on the dosage and the characteristics of the affection. The acute form of radiation sickness may be developed by exposure to large, often single doses of radiation (for example, when an accident occurs or during nuclear explosion). However, this type of injury is very rarely encountered under working conditions.

It is possible for the chronic form of radiation sickness to develop when an individual works for a long period of time under conditions involving exposure to doses which exceed the maximum permissible dose. This sickness is a disease of the entire organism, entailing affections of various of its systems and organs.

Exposure to excessive doses of ionizing radiation can result in the development of a series of pathological changes in the organism,

these being observed at definite times after irradiation. In experiments on animals, a number of authors (E.B. Kurlyandskaya, N.S. Boyko, V.A. Sanotskiy, et al.) observed a change in the reactivity of the organism both to physical and chemical agents and to infective toxins.

The long-range consequences of exposure to ionizing radiations require that we pay particular attention to the establishment of maximum permissible doses.

Under certain circumstances, the development of radiation sickness in persons working with sources of ionizing radiation and radioactive materials can be prevented.

The basic condition of radiation safety for the work of professional personnel is the observance of all necessary prophylactic measures to ensure that the work will not involve exposure to doses exceeding the maximum permissible doses. The following sections of this manual deal in detail with the methods and materials used to ensure radiation safety under conditions of contact with various types of ionizing radiation.

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[Footnote]

17 From the book Patologicheskaya fiziologiya ostroy luchevoy bolezin [The Pathophysiology of Acute Radiation Sickness], by P.D. Gorizontov (Medgiz [State Publishing House for Medical Literature], Moscow, 1958).

Chapter 3

BASIC FORMS OF RADIATION EXPOSURE

When working with radioactive substances and other sources of ionizing radiation, many radiation factors may affect the personnel handling them. These include the different types of penetrating radiations (γ- and β-rays, neutrons), radioactive aerosols and gases, and contamination of the integument, work clothes, the surfaces of equipment, and the work areas themselves with radioactive substances.

We may differentiate two ways in which ionizing radiations affect the organism: external irradiation with penetrating types of radiation and internal irradiation. Radioactive substances can penetrate into the organism by inhalation, the accidental transfer of these substances to the oral cavity from contaminated hands being of lesser importance. Many radioactive substances, especially those which form soluble compounds, penetrate through the skin. It is customary to call the simultaneous influence of external and internal irradiation or of several types of ionizing radiations (γ- and β-rays, γ-rays and protons) combined exposure.

When working with shielded sources, occupational exposure is limited to external irradiation. External irradiation is the main factor for experimental reactors, atomic power stations, and charged-particle accelerators.

When working with unshielded radioactive substances, conditions are generated for the penetration of radioactive substances into the organism, as well as for external irradiation. When high-activity

α-radiating substances are used, internal irradiation often is of predominant importance.

Basic information on the possible factors of occupational exposure and the sources of this exposure are given below.

RADIOACTIVE AEROSOLS

Radioactive aerosols are formed when working with radioactive substances in powder or solution form. The entry of radioactive aerosols into the respiratory organs and their prolonged retention in the organism determines to a considerable degree the possibility of injury to persons working with radioactive substances.

In contrast to inactive aerosols, which are formed only as a result of the mechanical pulverization of solid or fluid substances or during the condensation of supersaturated vapors, radioactive aerosols can also be formed by specific methods characteristic only of radioactive elements.

G.L. Natanson differentiates four basic modes of radioactive aerosol formation.

The first of these is the formation of active aerosols during the mechanical, metallurgical, and chemical processing of active ores and radioactive isotopes. Such processing includes the chemical separation of the fission products of uranium and plutonium, the treatment of radioactive wastes, etc. The formation of radioactive aerosols during these processes proceeds in the same fashion as for inactive elements.

The three remaining methods are characteristic only of radioactive elements.

The natural radioactive substances — radium, thorium, and actinium — form gaseous radioactive emanations (radon, thoron, and actinon) when they decay. These gases, passing into the air and de-

caying, form solid daughter products and create radioactive aerosols. In this case, the active aerosols may be formed either by adsorption of the decay products of the emanation by the ordinary aerosols which are always found in the air or by direct volume condensation. Under industrial conditions, this is the method by which the "radioactive deposits" which form on the surfaces of equipment and structural components are formed.

In those cases of radioactive decay where the final products are radioactive, radioactive aerosols may be formed by the knocking-out of active recoil atoms into the air. The mean free path of recoil atoms in air at normal pressure is approximately 0.1 mm. The further migration of such atoms in air proceeds in accordance with the laws of diffusion.

In those cases where the recoil atoms produced during α-decay are not radioactive, they may be mechanically carried along by the particles of the radioactive mother substance, forming radioactive aerosols of the initial product. This mode of radioactive aerosol formation is characteristic of polonium, radium, plutonium, and other elements and is called "aggregate recoil."

When working with α-radiating radioactive substances, the formation of active aerosols can thus occur not only when the initial product is being acted upon in some fashion (mechanical pulverization, volatilization, etc.), but even when no external influence is being exerted on the α-radiator. The possibility of spontaneous formation of radioactive aerosols requires that additional measures be taken to prevent the entry of radioactive substances into the air of work areas.

When working with radioactive substances, the extent to which dust is retained within the organism becomes of particular importance,

determining to a substantial degree the dose of ionizing radiation which the surrounding tissue receives from the radioactive substances. Definite laws linking the degree of accumulation and the retention of dust in the respiratory organs have been established in experimental work conducted principally with inactive dust; these laws are completely applicable to radioactive aerosols as well.

It has been shown in the works by Ye.A. Vigdorchik, Lendal (Landahl), Dotrband (Dautrebande), M.V. Pavlova, I.I. Livshits and his colleagues, and others that the degree, depth, and duration of the retention of aerosols in the respiratory organs depend on a number of factors. The most important of these are the size of the particles and the nature of respiration. In particular, it has been established that, with a normal frequency of respiration, dust particles 3-5 μ in size are retained almost completely in the upper respiratory tract. Only a small quantity of particles 0.2-0.3 μ in size is retained. The degree to which these particles are retained does not exceed 25-30%. The degree of retention of submicroscopic particles less than 0.1 μ in size is again greater, varying from 60 to 90%. When the frequency of respiration increases and the volume of air inhaled decreases, the degree of retention of particles of any size decreases. Particles no greater than 1-1.5 μ in size penetrate into the alveoli, the degree of dust retention in the alveoli reaching 90% and being independent of the frequency of respiration.

Khul'tkvist (Hultqust), summarizing a great deal of experimental material, compiled a diagram showing the retention of dust particles in the respiratory organs (Fig. 2).

In addition to the factors mentioned above, the electrical charge on the particles, their concentration in the inhaled air, and their hygroscopity have a definite influence on the degree to which

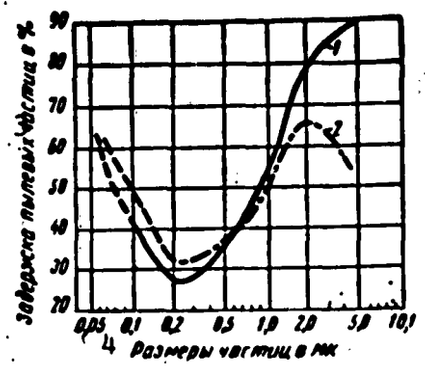

Fig. 2. Retention of dust particles as a function of their size (after Khul'tkvist). 1) In the respiratory tract; 2) in the lower branches of the respiratory tract; 3) retention of dust particles, in %; 4) particle size, in %.

dust is retained in the respiratory organs.

I.I. Livshits and his colleagues showed that, all other conditions remaining identical, 70-74% of particles bearing a charge were retained, while only about 10-16% of uncharged particles were retained. Of the total number of particles retained, 82-93% were charged.

The problem of the significance of the hydroscopity of dust and its concentration in the inhaled air has not as yet been sufficiently well studied, but there are indications that the percentage retention increases as the concentration and hygroscopity of the dust increase.

From the hygienic viewpoint, definite significance attaches to a high degree of radioactive aerosol ionization, this being a consequence of the specific conditions under which electrical charges develop on the dust particles.

According to the data of G.L. Natanson, radioactive aerosol particles can acquire a charge as a result of radioactive decay (the emission of charged α- and β-particles), the initial particle acquiring a positive charge in this case. A large percentage of recoil atoms are also positively charged. The percentage of charged particles for RaA and RaB in air reaches 82-93%. A high percentage of charged particles in radioactive aerosol systems obviously cannot help but have an effect on the retention of radioactive particles in respiration.

From a hygienic standpoint, the most important property of radioactive aerosols is their extremely high biological activity, this resulting in a great practical importance attaching to very low concentrations (by both weight and number) of radioactive aerosols in the air. The presence of 40 0.1 μ particles per m^3 of air is sufficient to produce the maximum permissible concentration of Sr^{89}, while the maximum permissible concentration of one of the most toxic nonradioactive substances – lead – can be obtained only by the presence of $2 \cdot 10^3$ particles of the same size per m^3 of air. This illustration serves to emphasize the importance of concentrations of radioactive aerosols in air which are so low that they are of no significance whatsoever for any other case.

In connection with this property of aerosols, we should note the fact that, while the biological harmfulness of very toxic substances is approximately proportional to the mass of these substances retained in the organism, the activity of the particles of radioactive aerosols and, consequently, their radiotoxicity is to a great extent a result of the number of particles and not of their mass. This is explained by the fact that fine radioactive particles are easily adsorbed by coarser particles of an inert substance, this causing a decrease in the specific activity of the coarse particles. For all practical purposes, the activity of particles of different sizes is not as a rule proportional to their mass.

In the light of this hypothesis, as was pointed out by Stennard, fine high-activity particles 0.1-0.3 μ in size, and especially submicroscopic particles, when present in high concentration present a definite danger of being taken into the respiratory organs even if their mass is only a minimal portion of that of all dust deposited in the lungs.

This fact is taken into account when establishing the maximum permissible concentrations of radioactive substances.

When radioactive substances enter the respiratory organs, the degree to which the latter are damaged depends to a considerable degree on the time for which the radioactive particles have been retained in the lungs, a factor which may be evaluated from the effective half-life of the substance in question. The retention of radioactive substances in the lungs is determined by their physical and chemical properties and varies within wide limits.

According to the data of Roy and Laurens (Roy, Lawrence) the effective half-life of boron decay products outside the lungs is 9 hours, while that of radium sulfate is, as Marinelli has shown, 3000 hours (125 days).

Both the chemical properties and the dispersion and concentration of the inhaled aerosol affect the length of time for which the dust is retained in the lungs. There are indications in the literature [La Bel' and Briger (La Belle, Briger)] that, in the intratracheal administration of uranium dust, increasing the concentration from 5 to 1500 μg or adding an inert dust leads to a more rapid cleansing of the lungs. At the same time, the authors found that, when the particle size increased from 0.3 to 11 μ, the time necessary to cleanse the lungs was reduced by a factor of more than 10. The upper respiratory passages, which retain the coarser particles, are cleansed relatively rapidly as a result of the action of the ciliary apparatus of the bronchi. Conversely, particles 1μ or less in size, which penetrate more deeply into the respiratory passages, along the alveoli, are retained therein for a long period of time. For example, plutonium particles have been detected in the alveoli 256 days after a single administration.

The use of special research methods (radiometry, autoradiography, et al.) has made it possible to study in greater detail the distribution, routes of expulsion, and ultimate fate of small concentrations of radioactive aerosols which enter the respiratory organs. It has been shown in experiments on animals that the particles of radioactive dust which reach the alveoli settle predominantly in the intra-alveolar and peribronchial tissues. Dust is cleansed from the deep passages of the lungs principally by phagocytes, a portion of which pass into the lumens of the bronchi and are removed from the lungs by coughing and sneezing, while the remainder pass along the lymph pathways into the regional lymph nodes.

The nature of the pathological changes caused by the action of radioactive aerosols taken in through the respiratory passages has been studied principally in experiments on animals. Work conducted by D.I. Zakutinskiy, Yu.A. Moskalev, L.N. Burykina, T.A. Kochetova, G.A. Avrunina, Tsember (Cember), Lisko and Finkel' (Lisco, Finkel), and others have shown that the intratracheal administration of such radioactive substances as $Ce^{144}F_3$, $Ru^{103}O$, $CrP^{32}O_4$, and $BaS^{35}O_4$ to rats causes severe inflammatory-sclerotic changes in the pulmonary tissue and metaplasia of the bronchial epithelium, this being accompanied by the subsequent development of bronchogenic cancer of the lungs. In this case, the irradiation dose which the lungs receive from the prolonged retention of the aforementioned substances at the site of administration is between 1500 and 30,000 rad.

In the light of these investigations, the development of sanitary measures directed both toward the elimination of sources of aerosol formation and toward the protection of the respiratory organs become of vast importance when working with radioactive substances.

RADIOACTIVE GASES

There is a large group of radioactive elements which occur in the gaseous state under normal environmental conditions. We must consider the radioactive α-radiating emanations (radon, thoron, and actinon) which are the products of the decay of the natural radioactive elements radium, thorium and actinium to be of prime importance among these. Radioactive emanations are always found in the atmosphere in moderate concentrations, of the order of 10^{-13} curies/liter of air (Khul'tkvist, 1959). Emanation concentrations greater than the natural level can occur in plants and laboratories which work with thorium and radium, in medical institutions which use radon, and in the mining, storage and processing of uranium and thorium ores.

The escape of emanations from the site at which they are formed depends on many conditions. The rate of emanation formation increases as the temperature of the materials being processed increases and is a definite function of their moisture content. When this moisture content is low, the diffusion coefficient of radon is $6.7 \cdot 10^{-2}$ cm^2/sec. When the moisture content increases to 15%, the diffusion coefficient decreases to $1 \cdot 10^{-2}$ cm^2/sec, while when the moisture content is 17%, this coefficient drops to $5 \cdot 10^{-3}$ cm^2/sec. This decrease in the diffusion coefficient as moisture content increases is caused by a decrease in the porosity of the medium and by absorption of the emanation by water. Intensive stirring, bubbling, and boiling will remove almost all of the gases from solutions of the salts of emanating substances.

Radioactive emanations decay comparatively rapidly. The half-lives of thoron and actinon are 54.5 and 3.92 seconds respectively; radon is characterized by a comparatively long half-life, 3.82 days. From the hygienicviewpoint, an important property of emanations is the forma-

tion of a series of solid radioactive elements, so-called active deposits, when they decay.

Radioactive emanations are similar in chemical properties to the inert gases and, when they enter the respiratory organs in inhaled air, they consequently are dissolved in the blood and tissue fluids, but do not participate in any biochemical reactions. The concentration of emanations in the blood is determined by their content in the air, being independent of exposure time; according to the data of Ruling and Sheminskiy (Scheminzky, 1954), this concentration for radon is approximately 30% of the concentration in the inhaled air. Penetrating into the blood stream, the emanations are carried to all tissues and organs, the entire body thus being subjected to virtually uniform irradiation with α-particles as a result of decay of the gases themselves and with α- and β-particles produced by the daughter products formed from the emanations within the organism. Emanations are eliminated from the organism through the respiratory organs, with the exhaled air.

In addition to emanations, the air always contains their short-lived daughter products in the form of highly dispersed solid radioactive aerosols. As is characteristic of aerosols in general, the decay products of emanations are retained in the organism during respiration. The irradiation dose which the respiratory organs receive from the decay products of emanations taken in with inhaled air is incomparably greater than that resulting from the decay of the gases themselves or of the daughter products which are formed within the organism. According to the calculations of L.S. Ruzer (1958), Kon and his colleagues (Cohn, 1953), Beyl and Shapiro (1955), and many other investigators, the irradiation dose which the respiratory organs receive from radon is only a fraction of a percent of the

dose produced by the accumulation and decay in the lungs of the active deposit of radon which is taken in with inhaled air. The critical organs with respect to irradiation dose for radioactive emanations are thus the respiratory organs. As a result, the action of inhaled emanations is accompanied by radiation injury to the respiratory organs, in addition to its ordinary radiation effect on the organism. In acute poisoning, toxic radiation pneumonia develops (Pinus, 1957). V.S. Kushneva (1957) noted that radon has a sclerosal effect on pulmonary tissue in chronic cases. It is known that there was a high incidence of lung cancer among the miners of the Joachimsthal and Schneeberg uranium mines during the 1930s. It has now been established that the etiological factor of this disease was prolonged inhalation of radon.

When working with emanating substances, the possibility of the passage of emanations into the air of the work areas depends on the nature of the technological processes and the design characteristics of the equipment. The most unfavorable operations in this respect are those of opening ampules containing radium, mesothorium, or radon and those involving solutions which have been in closed vessels for long periods of time. Under these conditions, the large quantity of emanations which has accumulated during the storage period is instantaneously released into the air. These operations must necessarily be carried out in airtight facilities. Even the setting up of high-velocity (1.5-2 m/sec) air movements across the openings of unenclosed equipment will not prevent contamination of the air of the work area with radon at the instant that the radium-containing ampule is opened.

It should be noted that contamination of the air of the work areas with emanations can occur not only as a result of the escape of

the gases themselves from the equipment, but also through deposition of the emanating mother elements on equipment surfaces, building components, instruments, clothing, work gloves, etc. It is consequently necessary that equipment used in the handling of emanating elements be hermetically sealed to the greatest possible degree in all cases.

The other group of radioactive gases includes the gaseous products formed in the fission of uranium in reactors. This group comprises the radioactive isotopes of xenon and krypton; radioactive I^{131}, which has a half-life of 8 days, and the radioactive gas Ar^{41}, which has a half-life of 110 minutes. The latter is formed when the stable Ar^{40} of air is bombarded with neutrons as it passes through the core of a reactor.

The fission of a uranium nucleus is accompanied by the formation of various isotopes of xenon and krypton. The most important of these from the hygienic standpoint are the isotopes with comparatively long half-lives: Kr^{85}, whose half-life is 9.4 years, and Xe^{133} and Xe^{135}, whose half-lives are 5.2 days and 9.13 hours respectively. It is important to note that radioactive isotopes of cesium are formed during the decay of these isotopes of xenon. The lifetimes of other isotopes of xenon and krypton are measured in minutes or seconds. Among these we should note the isotopes of krypton which have the atomic numbers 89 and 90, these being transmuted into Sr^{89} and Sr^{90} respectively when they decay.

Argon, xenon and krypton are inert gases and their behavior in the organism is analogous to that of the radioactive emanations described above. Iodine is a bioelement and, as we know, the organ in which it preferentially accumulates is the thyroid gland. The gases listed above are β-radiators and are dangerous as sources of internal irradiation. I^{131} and Ar^{41} are also sources of γ-radiation. The

presence of these gases in the atmosphere is also accompanied by external γ-irradiation. This is especially true of Ar^{41}, the danger from which is determined to a greater degree by γ-radiation than by β-particles. Since they differ in mode of origin, radioactive gases can enter the air of work areas from the core of a reactor under different conditions. It is possible for Ar^{41} to escape during the normal operation of a reactor, through various leaks in its shielding. The radioactive isotopes of krypton, xenon, and iodine are formed in the uranium slugs themselves and the possibility of their escaping into the work area results from incomplete sheathing of the heat-evolving elements. In this case, it is most probable that isotopes with comparatively long half-lives will escape. Radioactive gases, primarily Ar^{41}, form the major portion of the radioactive wastes which reactors discharge into the atmosphere.

Radioactive gases are formed during the operation of accelerators which have high neutron flux yields (devices of the cyclotron type); these gases include N^{16}, which has a half-life of 7.4 seconds, O^{15}, which has a half-life of 118 seconds, and others. The concentration of radioactive gases in the area of the cyclotron does not usually exceed 10^{-11} curie/liter. The gases formed have short half-lives and it is consequently permissible to enter the cyclotron room 10 minutes after the installation has been shut down.

Radioactive gases are of great importance as a radiation hazard factor in the production of artificial radioactive isotopes and their salts. Included in this category are the production of radioactive iodine by the irradiation of stable tellurium, the production of various organic compounds tagged with radioactive S^{35}, C^{14} et al., and so forth. In these cases, the intermediate products of the technological process are in the gaseous state.

It is necessary to dwell on the characteristics of the radioactive gas tritium.

Tritium (H^3) is a radioactive isotope of hydrogen; its half-life is 12.46 years and it emits very soft β-radiation whose maximum energy is 0.019 Mev. The β-particles emitted by tritium can be stopped by a layer of aluminum with a thickness of 0.28 mg/cm^2. Penetrating into the organism, tritium is oxidized to water and is incorporated into tissue structures during the metabolism process, in the same fashion as the stable light isotope of hydrogen H^1. As a result, tritium is used as a tracer for studying water and hydrogen metabolism (K.M. Bogdanov, M.I. Shal'nov, Yu.M. Shtukkenberg, 1959). Tritium is easily adsorbed by various materials, including glass and metals. As a result, when the air of a room is contaminated with tritium, it is possible for it to be adsorbed by the structural materials and then to gradually be desorbed, i.e., again contaminate the air. The penetration of tritium into the organism is dangerous. Tritium is of no importance as a source of external irradiation, since its radiation is of very low energy.

Stricter requirements with respect to the hermetic sealing of equipment and the establishment of intensive ventilation of work areas must be imposed on the organization of work involving the formation of radioactive gases.

GAMMA-RADIATION

An overwhelming number of radioactive transmutations are accompanied by the emission of γ-quanta of various energies. Many artificial radioactive isotopes such as Co^{60}, Ir^{192}, Na^{24}, Fe^{59}, etc. and certain natural radioactive elements emit γ-rays as a result of the transition of their nuclei to a more stable state. The energies of γ-rays emitted during radioactive decay vary from 0.02 to 5 mev.

Gamma-rays with high energies, of the order of 10-20 Mev, can be produced during nuclear reactions. Superhard γ-rays with energies of hundreds of Mev can be produced when high-energy electrons are slowed down in charged-particle accelerators; this γ-radiation has a pulse-like character.

As was indicated above, γ-radiation has a high penetrating power which depends directly on the energy of the γ-rays. As a result of its high penetrating power, γ-radiation is an especially dangerous factor in external irradiation. On the other hand, γ-radiation presents less of a danger as a factor of internal irradiation as a result of the low ionization density which it generates in the medium through which it passes.

It is necessary to keep in mind the possibility that high-intensity γ-fields may develop when working with experimental reactors and atomic power installations, where a large quantity of fission products is formed during the fissioning of uranium; these products are massive sources of γ-radiation. All work associated with the processing and disposal of these products is also accompanied by irradiation with γ-radiation.

In particular, the dose power of the γ-radiation above an unshielded experimental reactor can reach 1000 μroentgens/sec, while an irradiated heat-evolving element sets up a γ-field about itself which has a dose power of the order of several thousand microroentgens per second, even after a long period has elapsed.

The different types of tanks and tubing in which radioactive substances are stored or transported are also sources of γ-radiation. High-intensity (up to several hundred microroentgens per second) γ-fields are set up by the connections of the radioactive coolant circuit, as a result of induced radioactivity.

It is necessary to consider the possibility of exposure to external irradiation when working with γ-radiating isotopes, when transporting them, when using them in γ-materiology, and when employing them in medical practice.

Materials containing elements with high atomic weights – lead, iron, pig iron, etc. – are used for protection from γ-radiation, since they absorb γ-rays to the greatest degree. In experimental reactors and in other cases where it is not necessary to impose strict limitations on the size of the γ-radiation shielding, it is possible to use lighter and cheaper materials such as water, concrete, sand, etc.

BETA-RADIATION

Beta-decay is characteristic of the majority of natural and artificial radioactive elements. Under industrial conditions, both the actual radioactive isotopes which are widely used for certain purposes and equipment, structural materials of the work area, and clothing contaminated with radioactive substances may be sources of β-radiation.

Beta-radiation is of special importance in atomic power stations, experimental reactors, and various types of accelerators because of the induced radioactivity which it sets up in the equipment; this induced radioactivity can be a substantial source of β-irradiation for the operating personnel.

As was indicated above, the mean free path of β-particles in air depends on their energy and varies from fractions of a millimeter to several meters.

The low-energy β-rays from such radioactive substances as S^{35} (E = 0.16 Mev), Ru^{103} (E = 0.21 Mev), and Ca^{45} (E = 0.25 Mev) are almost completely absorbed by walls fabricated from ordinary glass or from a plastic tar containing a radioactive substance. We may

consequently assume that particles with energies of less than 0.2 Mev are of no practical importance as a factor of external irradiation.

The hard β-rays emitted by such radioactive isotopes as P^{32}, Sr^{89}, Y^{90}, etc., can generate high-intensity β-fields, exposure to which is accompanied by external irradiation of the personnel involved.

As has been established by our investigations, the percentage of β-radiation in the total dose of β-contamination of an induced nature is, on the average, 30-34%, this percentage increasing to 35-40% of the total dose in contamination with fission products.

In those cases where it is impossible to ensure protection from β-radiation by increasing the distance from the source, it is expedient to use special screens fabricated from materials with a low atomic weight, these including organic glass, plastics, etc. The use of these materials is preferred, since the x-radiation generated in the shielding material by its bombardment with β-particles is least intense in this case.

When working with β-radiators, the correct organization of work, the use of special shielding, and increasing the distance from the source can thus completely eliminate the danger of external irradiation.

The action of β-particles is not limited to external irradiation. When working with unshielded β-active substances, it is possible for them to enter the air in the form of gases, vapors, and aerosols. The greatest danger in this case lies in their entering the organism, where they are localized in certain organs and tissues, forming local nuclei of internal irradiation.

NEUTRON RADIATION

Neutron radiation has a high penetrating power as a result of the absence of an electric charge. In contrast to the other types of pene-

trating radiations, neutrons enter into nuclear reactions with the atoms of matter and can thus form radioactive isotopes. The formation of radioactive isotopes under the action of a stream of neutrons is called induced radioactivity and is an additional danger when working with neutrons.

High-power neutron fluxes are produced in charged-particle accelerators, especially in those which accelerate protons and deuterons (cyclotrons, linear accelerators, and electrostatic generators). When the accelerator is operating, the fast neutron flux may reach several thousand neutrons per centimeter^2-second.

In atomic power stations, the thermal neutron flux in the central uranium-graphite reactor chamber can reach 1700 neutrons/cm^2-sec. In addition to the reactor itself, the experimental holes for extracting neutron beams are also sources of neutrons in an atomic power station. As a rule, neutrons are emitted while the reactor is operating. Neutron radiation completely ceases when the reactor is shut down.

Neutron radiation may also be produced by the shielded neutron sources (radium-beryllium and polonium-beryllium) which are used for the neutron logging of petroleum in geology, for determining the quality of graphite in reactor building, and in various types of biological and medical research work.

The presence of high-power neutron fluxes may result in the activation of structural elements, equipment, individual components, and the air, all of which become secondary sources of β- and γ-radiation. The direct action of neutron fluxes on the organism can cause activation of a number of elements which enter into the composition of tissue (sodium, sulfur, phosphorus, etc.).

Water, paraffin, graphite, and special types of concrete are most frequently used for shielding from neutron radiation, since neutrons pass easily through lead and other heavy metals, but are

quite well moderated by light hydrogen-containing materials. Boron and cadmium are used to absorb slow neutrons.

CONTAMINATION OF ROOMS, EQUIPMENT, CLOTHING, AND THE INTEGUMENT WITH RADIOACTIVE SUBSTANCES

Contamination of the external surfaces of equipment, the structural elements of work areas, and the clothing and integument of operating personnel with radioactive substances form a substantial part of the sum of the factors of occupational radiation exposure.

Contamination of the hands and clothing of operating personnel occurs chiefly during the execution of manual operations, as a result of direct contact with a radioactive substance or contaminated equipment. Many radioactive elements (strontium, radium, plutonium, thorium, phosphorus, etc.) penetrate uninjured skin. Radioactive substances can be transferred from contaminated hands into the oral cavity. In addition, contamination of clothing and the integument is a source of irradiation of the skin with α- and β-particles.

Radioactive contamination of work areas and equipment can occur in many ways. The highest level of contamination results from the direct deposition of radioactive substances on certain surfaces when powders diffuse or solutions spill, during repair work or when equipment is being dismantled, etc. The contact transfer of radioactive substances by the contaminated hands, gloves, or shoes of personnel is also of considerable significance. The precipitation of radioactive aerosols on these surfaces is of somewhat lesser importance. Radioactive contamination can also occur in specific ways which are characteristic only of radioactive substances; these include contamination of the sheathing of the heat-evolving elements in reactors and of the structural components of high-energy particle accelerators as a result of induced activity, the formation of a radioactive de-

posit on the surfaces in areas contaminated by emanations, this resulting from the deposition of active deposits of these emanations, etc. In the latter case, contamination of these surfaces is not of material hygienic significance, since it does not reach high levels and its activity on the surfaces is caused by short-lived elements.

Radioactive substances adsorbed by various materials are sources of radioactive aerosols and gases, streams of β-particles, and γ-radiation, as well as an additional source of contamination of the hands, clothing and shoes of personnel. Highly active α-emitting elements present the greatest danger with respect to ability to form aerosols.

When surfaces are contaminated with β-active substances, whose capability of spontaneously forming aerosols is less than that of α-radiators, streams of penetrating radiations – high-energy γ-rays and β-particles – become of primary importance.

The contamination of exposed surfaces by emanating elements such as radium and thorium is of basic significance. In this case, both the radioactive mother substances and their radioactive daughter gases, radon and thoron, may enter the air. Streams of β- and γ-radiation can develop from materials contaminated with radium and thorium, which themselves are almost entirely α-radiators. This is explained by the fact that β- and γ-radiating daughter products are formed during the decay of the radon and thoron which remain within the contaminated materials.

For example, according to our data, the dose power of the γ-radiation from the field in a laboratory room contaminated with radium was thus 10-50 μr/sec. The concentration of radium aerosols in the air of this room was $2 \cdot 10^{-13}$ curie/l, while that of radon aerosols was $2.3 \cdot 10^{-10}$ curie/l. In this case, the contamination of the air was

entirely due to the presence of radium on the exposed surfaces.

Radioactive substances adsorbed by various materials are thus potential sources of internal irradiation and sources of external streams of penetrating radiations. At high levels of contamination, this factor can of itself cause the overexposure of operating personnel.

In conclusion, we should note that radiation factors act in various combinations under occupational conditions and that they frequently generate one another. For example, the presence of high-power neutron fluxes in accelerators and nuclear reactors thus leads to the creation of induced activity of equipment components, the air, etc., the deposition of radioactive substances on exposed surfaces causing contamination of the air with radioactive aerosols and gases, as well as resulting in the formation of streams of β- and γ-radiation in the rooms involved. The task of sanitary supervision is not only the quantitative consideration of exposure to radiation, but also the study of the sources and causes of this exposure and the explanation of the relationships among individual factors of irradiation, in order that there be a firm basis for the development of effective sanitary measures.

Chapter 4

MAXIMUM PERMISSIBLE IRRADIATION DOSES AND CONCENTRATIONS OF RADIOACTIVE SUBSTANCES IN AIR AND WATER

The term maximum permissible is used to refer to those concentrations of radioactive substances and irradiation doses which are not sufficient to cause any pathological changes or illnesses detectable by present methods of examination in personnel systematically exposed over an infinitely long period of time.

Several methods are used to establish maximum permissible irradiation levels. The most valuable data on which to base maximum permissible doses are material on the influence on man of small doses and low concentrations. The gathering of such data requires prolonged observations of the condition of healthy individuals who are in contact with radioactive substances and comparison of the data obtained with the doses and concentrations to which these persons were subjected.

However, little data of this type has been cited in the literature. The study of this problem presents great difficulties as a result of the necessity for prolonged observation and constant precise recording of the irradiation dose, the complexity of studying the influence of radiation on human heredity, etc. It is consequently necessary to resort to other methods, i.e., to the toxicological and computational methods.

The toxicological method includes experimental investigations of the toxicity of radioactive substances for animals as well as the study of the influence of various types of radiation in external ir-

radiation. The maximum doses which cause no changes in animal organisms and do not affect their heredity over a long period of time have been established.

Data from experimental investigations of the effects of osteotropic radioactive substances on animals are in accordance with clinical observations of the sarcomogenic action of incorporated radium on man.

With the introduction of corrections, the calculated apparent sensitivity of various animals to radiation and data from toxicological experiments can serve as valuable material on which to base maximum permissible doses.

The computational method is based on the determination of that irradiation dose which, over a 24-hour period, does not set up a dose in any organ which exceeds the safe dose. For incorporated substances, this calculation is carried out for the site of greatest irradiation, the so-called critical organ in which isotopes are concentrated to the greatest extent. In this case, the energy and type of radiation, the method by which it enters the organism, the distribution and rate of excretion of the substance, its half-life, etc., are taken into account.

The first attempt to establish a radiation dose by measuring it with the aid of x-ray film was made by Rollins in 1902. As was later shown, the dose which he suggested, determined from the blackening of the film, corresponded to approximately 10 r per day.

In 1925, Matcheller (Mutscheller) used observations of the condition of a healthy individual subjected for a prolonged period to the action of ionizing radiation as the basis for establishing that doses of from 0.1 to 0.2 r per day had no detrimental effects on persons working under these conditions for several years. In 1928,

the International Commission on Radiation Protection was organized and charged with the responsibility of developing recommendations for radiation safety norms. This Commission established the roentgen (r) as the unit dose of x-rays.

As the areas in which radioactive substances and ionizing radiations were used expanded, the number of experimental investigations and observations of human beings increased, this facilitating the accumulation of scientific knowledge on the effects of ionizing radiation. These permitted the International Commission on Radiation Protection to recommend a maximum permissible dose of 0.2 r per day or 1 r per week for x-rays and γ-radiation in 1934; in 1936, the maximum permissible dose was reduced to 0.1 r per day.

It was established on the basis of the investigations described above that the dose of 0.1 r per day was calculated without the necessary safety factor and that serious changes in the organism resulted if this level was exceeded ten times during the course of a year. As a result of data amassed through 1950, the International Commission on Radiation Protection reviewed its findings and set 0.05 r per day and 0.3 r per week as the maximum permissible dose. It was simultaneously established that the permissible content of radium in the organism is 0.1 μg, this result being of material significance for other radioactive substances.

In the USSR, the maximum permissible concentrations of radioactive substances and doses of ionizing radiations are established by the Ministry of Public Health USSR and are changed as new data on the effects of these factors on the human organism are gathered.

Before 1950, 0.1 r per working day was taken to be the maximum permissible dose; in 1950, this dose was halved (to 0.05 r per working day). According to international recommendations, the basic permissible

dose is assumed to be 0.3 r per week. In the Soviet Union, 0.05 r is taken as the basic daily dose, this being based on the assumption that fractionated doses are less dangerous than concentrated doses. At the same time, taking into account the possibility that the daily dose may be exceeded in individual cases, a maximum permissible dose of 0.3 r per week has been established, this corresponding to a permissible total yearly dose of 15 r.

The improvement of experimental techniques and methods and the new experimental approach to the study of the influence of ionizing radiations and radioactive substances has made it possible to obtain interesting new data. Radiation doses have come to be expressed in terms of the roentgen equivalent biological (reb) and this makes it possible to take into account all types of radiations.

In July 1959, the International Commission on Radiation Protection considered and confirmed new recommendations for the maximum permissible concentrations of radioactive substances in water and air. In accordance with these recommendations, the maximum permissible dose was reduced to 0.1 reb per week.

In establishing the maximum permissible doses, the International Commission on Radiation Protection proceeded from the following definition: "Any variation in the environmental conditions in which man lives can involve a danger of detrimental consequences. On this basis, it is assumed that prolonged constant exposure to ionizing radiations added to the natural background radiation presents a certain danger. However, man cannot be completely prevented from using ionizing radiations and the practical problem thus consists in limiting the doses of radiation to that level which presents no danger to individual persons and to the population as a whole. This dose is also called the maximum permissible dose. The individual permissible dose is that dose

which, whether accumulated over a long period of time or received in a single irradiation, entails no probability whatsoever of serious somatic or genetic consequences so far as is now known."

In the Soviet Union, in accordance with Sanitary Specifications No. 333-60, the maximum permissible dose is now assumed to be 0.1 reb per week, which corresponds to a permissible yearly dose of 5 reb. This dose is for so-called occupational irradiation (Category A). The total occupational irradiation dose D over the entire work span, expressed in roentgen equivalents biological, must not exceed $D = 5 \cdot (N - 18)$ reb, where N is the age of the individual in years and 18 is the age at which occupational irradiation began.

In exceptional cases, when performing emergency work, it is permissible for the total yearly dose of external irradiation to be increased to 12 reb for a 30-year old man. This dose is added to the dose received at the instant in question and, if the total dose in this case exceeds the permissible dose determined from the formula $D = 5 \cdot (N - 18)$, the excess may be compensated for by decreasing subsequent irradiation over a period of five years.

Category B comprises the irradiation of persons working in rooms adjoining those in which work with radioactive substances and radiations is being conducted, but not working directly with them (administrative-clerical, employees', etc., rooms), as well as the irradiation of persons in rooms in the health-protection zone.

Category C includes the irradiation of persons of all age groups when such irradiation does not result from working with radioactive substances and when the persons involved live beyond the limits of the health-protection zone. When calculating the maximum permissible doses, the possibility of the continuous action of radiation over a 24-hour period is taken into account. The permissible dose of external

irradiation for Category B is 0.5 reb per year, while that for Category C is 0.05 reb per year, i.e., less by factors of 10 and 100 respectively than the permissible dose for occupational irradiation.

In accordance with the relative biological effect (RBE) established for different types of radiation, the permissible doses shown in rad/week in Table 4 have been adopted.

Public health legislation has also established maximum permissible dose powers, which correspond to a maximum permissible dose of 0.1 reb/week.

The permissible dose power for γ-radiation is determined from the formula P = 100/t, where P is the dose power in milliroentgens per hour and t is the number of work hours per week. The dose power of β-radiation is expressed as the number of β-particles per centimeter^2-second and is determined from the formula N = 700/t, where N is the number of β-particles and t is the time in hours per week.

TABLE 4

Maximum Permissible Doses (MPD) and Relative Biological Effect (RBE)

1 Вид ионизирующих излучений	2 ПДД, рад/неделя	3 ОБЭ
4 Гамма- и рентгеновы лучи	0,1	1
5 Бета-частицы и электроны	0,1	1
6 Протоны и α-частицы	0,01	10
7 Многозарядные ионы и ядра отдачи	0,005	20
8 Тепловые нейтроны	0,02	5
9 Быстрые нейтроны	0,01	10

1) Type of ionizing radiation; 2) MPD, rad/week; 3) RBE; 4) gamma- and x-rays; 5) beta-particles and electrons; 6) protons and α-particles; 7) multicharge ions and recoil nuclei; 8) thermal neutrons; 9) fast neutrons.

The maximum permissible γ-radiation dose for a six-hour work day is thus 2.8 mr/hr, while that for β-radiation is 20 β-particles/cm^2-sec.

For γ-irradiation of the hand, a dose exceeding the permissible

level by a factor of 5 is allowed, while the dose of β-particles may exceed the permissible level by a factor of 10, although this is on condition that the body be reliably shielded from radiation and receive no more than 0.1 reb/week. In adjacent rooms, where no work with radioactive substances is being conducted, the permissible level of external ionizing radiation fluxes is lower by a factor of 10 (0.01 reb/week).

The maximum permissible concentrations of radioactive substances in the air are determined from biological data which take into account the degree of absorption, distribution, excretion, and energy of the radiation, the half-life of the isotope, the solubility of its compounds, and the dispersion and degree of toxicity of the substance in question. When they enter the organism, radioactive substances act principally on those organs and tissues within which they accumulate to the greatest extent.

When establishing the maximum permissible concentrations of radioactive substances in the air, a great deal of attention is paid to the determination of the critical organ, accumulation of a radioactive substance within which leads to the most severe injury to the entire organism. Three groups of critical organs have been established, the distinction depending on the radiosensitivity of the organ and the degree of danger created by the accumulation of the radioactive substance within it.

Group I critical organs are the entire body, the gonads, the crystalline lens, and the hematogenous organs.

Group II critical organs are the muscles, adipose tissue, liver, kidneys, pancreas, prostate, gastrointestinal tract, and lungs.

Group III critical organs are the skin, thyroid gland, and the bones.

The maximum permissible internal irradiation doses shown in Table 5 have been established for the different categories of irradiation and groups of critical organs.

TABLE 5

Maximum Permissible Doses of External and Internal Irradiation

1	2		3					
			4					
	8	9	5		6		7	
A	0.1	5	0.1	5	0.3	15	0.6	30
10 Б	0.010	0.5	0.01	0.5	0.03	1.5	0.06	3
11 В	0.001	0.05	0.001	0.05	0.01	0.5	0.02	1

1) Irradiation category; 2) external irradiation; 3) internal irradiation; 4) critical organs; 5) first group; 6) second group; 7) third group; 8) reb/week; 9) reb/year; 10) B; 11) C.

When calculating the maximum permissible concentrations of radioactive substances, the different irradiation doses set up in the organ are thus used as the basis for the determination. In category A, 0.1 reb/week is used for Group I critical organs, 0.3 reb/week is used for Group II, and 0.6 reb/week is used for Group III. It may be seen from Table 5 that, for an entire population (Category C), the doses of external and internal radiation are less than those for occupational radiation by a factor of 100. The permissible irradiation for an entire population thus approximates the natural background. On recalculation for possible irradiation of the hands, these doses exceed the natural background by a factor of 10, this being safe according to present concepts. If the gonads are irradiated in accordance with the new maximum permissible levels, the dose received equals the natural background level and the total dose to the gonads is thus doubled. Within the limits of the health-protection zone (including all buildings within this zone), the maximum permissible

TABLE 6

Maximum Permissible Concentrations of Radioactive Substances (Summary from "Sanitary Specifications 333-60")

	1 Изотоп	2 Предельно допустимые концентрации, *кюри*			
		3 в воде открытых водоемов и источников водоснабжения	4 в воздухе производственных помещений	5 в атмосферном воздухе санитарно-защитной зоны	6 в атмосферном воздухе за пределами санитарно-защитной зоны
7	Тритий-3	$3 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-9}$	$7 \cdot 10^{-11}$
8	Углерод-14	$2 \cdot 10^{-7}$	$4 \cdot 10^{-9}$	$4 \cdot 10^{-10}$	$4 \cdot 10^{-11}$
9	Натрий-24	$8 \cdot 10^{-9}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-12}$
10	Фосфор-32	$5 \cdot 10^{-9}$	$7 \cdot 10^{-11}$	$7 \cdot 10^{-12}$	$7 \cdot 10^{-13}$
11	Сера-35	$7 \cdot 10^{-9}$	$3 \cdot 10^{-10}$	$3 \cdot 10^{-11}$	$1 \cdot 10^{-12}$
12	Хлор-36	$7 \cdot 10^{-9}$	$2 \cdot 10^{-11}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-12}$
13	Аргон-41		$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-11}$
14	Кальций-45	$3 \cdot 10^{-8}$	$3 \cdot 10^{-11}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-13}$
15	Хром-51	$5 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$
16	Железо-55	$3 \cdot 10^{-8}$	$3 \cdot 10^{-10}$	$3 \cdot 10^{-11}$	$1 \cdot 10^{-12}$
	Железо-59	$1 \cdot 10^{-8}$	$3 \cdot 10^{-11}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-13}$
17	Кобальт-60	$1 \cdot 10^{-8}$	$9 \cdot 10^{-12}$	$9 \cdot 10^{-13}$	$9 \cdot 10^{-14}$
18	Медь-64	$6 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-11}$
19	Цинк-65	$1 \cdot 10^{-8}$	$6 \cdot 10^{-11}$	$6 \cdot 10^{-12}$	$2 \cdot 10^{-12}$
20	Бром-82	$1 \cdot 10^{-8}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$	$2 \cdot 10^{-12}$
21	Стронций-89	$3 \cdot 10^{-8}$	$3 \cdot 10^{-11}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-13}$
	Стронций-90	$3 \cdot 10^{-11}$	$3 \cdot 10^{-13}$	$3 \cdot 10^{-14}$	$3 \cdot 10^{-15}$
22	Серебро-111	$1 \cdot 10^{-8}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$	$2 \cdot 10^{-12}$
23	Олово-113	$2 \cdot 10^{-8}$	$5 \cdot 10^{-11}$	$5 \cdot 10^{-12}$	$5 \cdot 10^{-13}$
24	Иод-131	$6 \cdot 10^{-10}$	$9 \cdot 10^{-12}$	$9 \cdot 10^{-13}$	$9 \cdot 10^{-14}$
25	Цезий-134	$1 \cdot 10^{-8}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-13}$
	Цезий-137	$1 \cdot 10^{-8}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-12}$	$1 \cdot 10^{-13}$
26	Золото-198	$1 \cdot 10^{-8}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$	$2 \cdot 10^{-12}$
27	Полоний-210	$2 \cdot 10^{-11}$	$1 \cdot 10^{-14}$	$1 \cdot 10^{-15}$	$1 \cdot 10^{-16}$
28	Торон-220		$1 \cdot 10^{-11}$	$3 \cdot 10^{-13}$	$1 \cdot 10^{-13}$
29	Радон-222		$3 \cdot 10^{-11}$	$1 \cdot 10^{-11}$	$3 \cdot 10^{-12}$
30	Радий-226	$5 \cdot 10^{-11}$	$3 \cdot 10^{-14}$	$3 \cdot 10^{-15}$	$3 \cdot 10^{-16}$
31	Торий-232	$1 \cdot 10^{-11}$	$2 \cdot 10^{-15}$	$2 \cdot 10^{-16}$	$2 \cdot 10^{-17}$
	Торий-232	0,1 *мг/л*	0,02 *мг/м³*	$2 \cdot 10^{-3}$ *мг/м³*	$2 \cdot 10^{-4}$ *мг/м³*
32	Уран-233—238	$3 \cdot 10^{-11}$	$2 \cdot 10^{-14}$	$2 \cdot 10^{-15}$	$2 \cdot 10^{-16}$
	Уран-238	0,05 *мг/л*	0,02 *мг/м³*	$2 \cdot 10^{-3}$ *мг/м³*	$2 \cdot 10^{-4}$ *мг/м³*

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1) Isotope; 2) maximum permissible concentrations, curie/liter; 3) in water of open reservoirs and water supply wells; 4) in air of industrial areas; 5) in atmospheric air of health-protection zone; 6) in atmospheric air beyond borders of health-protection zone; 7) tritium; 8) carbon; 9) sodium; 10) phosphorus; 11) sulfur; 12) chlorine; 13) argon; 14) calcium; 15) chromium; 16) iron; 17) cobalt; 18) copper; 19) zinc; 20) bromine; 21) strontium; 22) silver; 23) tin; 24) iodine; 25) cesium; 26) gold; 27) polonium; 28) thoron; 29) radon; 30) radium; 31) thorium; 32) uranium; 33) mg/l.

concentrations of radioactive substances in the air and the level of external irradiation are assumed to be less than those for occupational irradiation by a factor of 10. The maximum permissible concentrations in air and water thus calculated for the most widely used radioactive substances are shown in Table 6.

TABLE 7

Maximum Permissible Concentrations (MPC) of Radioactive and Toxic Substances in Air

1 Изотопы	2 Предельно допустимая концентрация		5 Число частиц радиусом 0,1 μ в 1 л при которых создается ПДК
	3 кюри/л	4 мг/л	
6 I. Радиоактивные вещества			
7 Натрий-24	$1 \cdot 10^{-10}$	$1{,}15 \cdot 10^{-14}$	0,038
8 Фосфор-32	$7 \cdot 10^{-11}$	$2 \cdot 10^{-13}$	0,017
9 Сера-35	$3 \cdot 10^{-10}$	$7 \cdot 10^{-13}$	0,2
10 Кальций-45	$3 \cdot 10^{-11}$	$1{,}5 \cdot 10^{-13}$	0,3
11 Стронций-89	$3 \cdot 10^{-11}$	$1{,}2 \cdot 10^{-13}$	0,12
12 Радий-226	$3 \cdot 10^{-14}$	$3 \cdot 10^{-11}$	1,2
13 Полоний-210	$1 \cdot 10^{-14}$	$2 \cdot 10^{-13}$	$7 \cdot 10^{-6}$
14 II. Нерадиоактивные токсичные вещества			
15 Пыль, содержащая до 70% свободной SiO_2		$2 \cdot 10^{-6}$	$2 \cdot 10^{6}$
16 Свинец и его неорганические соединения		$1 \cdot 10^{-6}$	$2 \cdot 10^{6}$
17 Бериллий и его соединения		$1 \cdot 10^{-6}$	
18 Ртуть		$1 \cdot 10^{-6}$	

1) Isotope; 2) maximum permissible concentration; 3) curie/liter; 4) mg/liter; 5) number of particles with a radius equal to 0.1 μ per liter necessary to set up MPC; 6) radioactive substances; 7) sodium; 8) phosphorus; 9) sulfur; 10) calcium; 11) strontium; 12) radium; 13) polonium; 14) nonradioactive toxic substances; 15) dust containing up to 70% free SiO_2; 16) lead and its inorganic compounds; 17) beryllium and its compounds; 18) mercury.

As may be seen from Table 6, especially low concentrations of radioactive substances in the air of work areas (10^{-15}-10^{-14} curie/l) have been established for α-radiators, which have the capability of concentrating selectively in certain organs and are excreted slowly from the organism.

The maximum permissible concentrations in the air of work areas for other radioactive substances vary from $1 \cdot 10^{-13}$ to $6 \cdot 10^{-8}$ curie/l. These concentrations correspond to extremely small quantities by weight of the radioactive substances in question.

It is necessary to point out that the permissible concentrations of radioactive isotopes in air is substantially less than for ordinary toxic substances and their compounds.

For purposes of comparison, the permissible concentrations in air for the most toxic substances and for radioactive isotopes are shown in Table 7, expressed in terms of quantity by weight.

From the data given in Table 7, it may be seen that the permissible content by weight in air for radioactive isotopes is less than that for a number of highly toxic chemical substances by a factor of 5-6 orders of magnitude and occasionally even more.

It should be carefully noted that there is a vast difference in the number of particles with a radius of 0.1 μ per liter of air necessary to produce the maximum permissible concentration.

Thus, for example, the presence of only one particle with a radius of 0.1 μ is sufficient to produce the maximum permissible concentration of sulfur ($3 \cdot 10^{-10}$ curie/liter) in air, while the maximum content in air of lead corresponds to the presence of $2 \cdot 10^5$ particles of the same size per liter.

When the radius of the particles increases or decreases from a value of 0.1 μ, the number of particles per liter of air necessary to generate the maximum permissible concentration decreases or increases correspondingly.

In order to convert concentrations from units of curies per liter to decays per minute per liter, it is necessary to multiply the values given in Table 7 by $2.2 \cdot 10^{12}$.

The maximum permissible content of radioactive substances in water is established by assuming that a human being consumes 2.2 liters of water per day. The permissible content of radioactive substances in food products of vegetable and animal origin is determined in such fashion that the total intake of radioactive substances in water and food per day does not exceed the maximum permissible concentration of radioactive substances in water multiplied by 2.2

(water consumption in liters per day).

In water from underground wells used for household and drinking purposes, the content of radioactive substances of purely natural origin is not permitted to exceed the maximum permissible doses for open reservoirs. The presence of artificial radioactive substances is not permitted.

There is often a mixture of radioactive substances having a known percentage composition in the air. In this case, the number of permissible doses (N) is determined from the formula

$$N = \frac{QP_1}{\text{ПДК}_1} + \frac{QP_2}{\text{ПДК}_2} + \cdots \frac{QP_n}{\text{ПДК}_n} = Q\sum_{i=1}^{n} \frac{P_i}{\text{ПДК}_i}.$$

where Q is the total activity of the mixture in curies per liter, P_1, P_2,..., P_n are the relative percentages by activity of the isotopes in the mixture, and PDK_1..., PDK_n are the maximum permissible concentrations for individual isotopes.

In accordance with required radiation safety, N should equal 1. Q for the mixture will then equal

$$\text{Q of mixture} = \frac{1}{\sum_{i=1}^{n} \frac{P_i}{\text{ПДК}_i}} \quad \text{curie/liter}$$

Limiting the level of contamination of the skin and clothing of operating personnel, as well as of the surfaces in the work areas, is of no small importance in the solution of problems associated with protection from radiation. When establishing the maximum permissible levels of contamination for these surfaces, not only the possibility of the entry of radioactive substances into the organism, but also the action of these substances as sources of external radiation are taken into account. Many of the possible factors involved in the action of radiation on the organism cannot be clearly traced and this level of contamination consequently cannot now be established with sufficient precision. Taking into account the fact that α-radia-

tors present a greater danger when they enter the organism than do β-radiators, lower maximum permissible levels have been established for the former.

Table 8 shows the maximum permissible contamination levels for work area surfaces, clothing, and the skin of the hands which have been adopted in the Soviet Union.

As may be seen from Table 8, the lowest contamination levels have been established for the skin of the hands, as a result of the probability that radioactive substances will be transferred from contaminated hands to a far greater degree than from other surfaces or from clothing. Contamination of other portions of the body is not permissible.

TABLE 8

Maximum Permissible Levels for the Contamination of Surfaces

	1 Число частиц, испускаемых в 1 минуту на 150 см²			
	α		β	
	2 до очистки	3 после очистки	до очистки	после очистки
4 Руки	75	Фон 11	5 000	Фон
5 Спецбелье и полотенца	75	»	5 000	»
6 Хлопчатобумажные халаты	500	100	25 000	5 000
7 Одежда из пластикатовой пленки	500	200	25 000	10 000
8 Перчатки	500	100	25 000	5 000
9 Спецобувь	500	200	25 000	5 000
10 Рабочие места и оборудование	500	200	25 000	5 000

1) Number of particles emitted per minute per 150 cm^2; 2) before cleaning; 3) after cleaning; 4) hands; 5) special linen and towels; 6) cotton coveralls; 7) clothing fabricated from plastic film; 8) gloves; 9) special shoes; 10) work area and equipment; 11) background.

Different levels of surface contamination have been established in foreign nations. In France, different levels of surface contamination have been adopted for "active" and "inactive" zones, taking into account the toxicity of isotopes. Converted, values of 3300 α-particles and 33,000 β-particles per 150 cm^2 have been adopted for

clothing and 1650 α-particles and 16,500 β-particles per 150 cm^2 have been adopted for skin.

In a summary of rules for the practical protection of persons subjected to ionizing irradiation, published in London, the following values have been adopted for the isotopes of greatest radiotoxicity (for convenience, these have been converted to 150 cm^2 per minute): body, personal clothing, hospital bed equipment of "inactive zone" - 3300 α-particles, 33,000 β-particles; protective clothing, "active" laboratories, glass vessels, instruments - 33,000 α-particles and 330,000 β-particles.

The maximum permissible contamination levels adopted abroad thus differentiate to a lesser degree and permit substantially higher contamination than those used in the USSR.

Establishment of the maximum permissible surface contamination levels is of great disciplinary value. We may now say with certainty that observance of the maximum permissible contamination levels for surfaces, hands, and clothing adopted in the USSR ensure that this factor of radiation exposure is reduced to safe proportions.

The public health laws of the USSR provide for the creation of conditions under which the total dose from all types of ionizing radiations at the work site, as well as from radioactive substances in the air, will not exceed a single maximum permissible dose, i.e., 0.1 reb/week. If this total irradiation dose is exceeded, the resulting level can be reduced to the maximum permissible dose by reducing the level of a certain type of ionizing radiation, which type this is depending on technological, design, or economic considerations.

Different opinions are expressed in the literature with respect to the determination of the total doses received by man under the action of several types of radiation. This problem requires further

serious study and experimental groundwork.

N.G. Gusev (1959) presents a method for calculating the total radiation doses for various occupational conditions, these being based on a combination of the internal and external irradiation doses.

In the opinion of Bernes (Barnes), doses of different types of external irradiation can be summed when they are expressed in roentgen equivalents biological. Speaking of the combined effect of radiation, Bernes shows that, in many cases, combining the doses yields a higher tissue dose than is actually received. At the same time, the intensified biological effect can be summed. Bernes, while not denying the synergism of this effect, believes that it can hardly be of any importance. In this connection, he recommends that definite limits on internal and external irradiation be observed independently, as specific quantities.

In accordance with the computational method adopted in the USSR, total irradiation doses are expressed in roentgen equivalents biological, since relative biological effect coefficients are less instructive in terms of the existing norms. As a result, doses of different types of external radiation may be summed.

When it is necessary to calculate the radiation dose caused by radioactive substances in the air, it should be kept in mind that the concentration of radioactive substances in the air (Q_0) is calculated for a daily 7-hour stay in an area of contaminated air. If a worker stays in an area of contaminated air for a period longer or shorter than 7 hours, which equals t, the permissible concentration Q_t is

$$Q_t = Q_0 \frac{7}{t}.$$

In the presence of mixed external fields of ionizing radiations and mixtures of isotopes with known percentage compositions, complete radiation protection may be obtained by satisfying the condition

$$Q = \sum_{i=1}^{n} \frac{P_i}{\text{ПДК}_i} + \frac{D_\gamma + D_{t.n.} + D_{b.n.}}{D_0} = 1,$$

where D_γ, $D_{t.n.}$, and $D_{b.n.}$ are the actual (real) dose powers in mreb/week for γ-rays, thermal neutrons, and fast neutrons respectively, D_0 being the maximum permissible dose power in mreb/week.

For external radiation, the permissible levels of contamination result in doses which are substantially less than the maximum permissible doses and they consequently cannot be summed with other doses resulting from external ionizing radiation fluxes and concentrations of radioactive substances in the air. However, these doses must be taken into account, since they play a decisive role as factors of radiation exposure.

It should be remembered that many isotopes may remain in the human body for months and even years. There is as yet no satisfactory method which has any material tendency to accelerate the excretion of radioactive substances from the organism. At the same time, it should be noted that present knowledge does not make it possible to completely refute the theory which holds that any dose of ionizing radiation can cause certain genetic or somatic harm. The maximum permissible concentrations of radioactive substances in water and in the air which we now use were established without taking into account the food chain.

As a result of the stated content of radioactive substances in the air and the maximum permissible doses of external irradiation, we cannot judge our external environment to be optimum and we should consequently take all possible measures to ensure a maximum reduc-

tion of these concentrations and irradiation levels. It is wise to consider the maximum permissible concentrations as maximum quantities rather than means, this being the greatest guarantee of safety.

Manuscript Page No.	[List of Transliterated Symbols]
63	т.н. = t.n. = teplovyye neytrony = thermal neutrons
63	б.н. = b.n. = bystryye neytrony = fast neutrons

Section 3

INDIVIDUAL PROTECTION DEVICES, PERSONAL HYGIENE, AND PROBLEMS OF DECONTAMINATION

Chapter 1

INDIVIDUAL PROTECTION DEVICES

The term individual protection devices is customarily used to refer to clothing, shoes, and various instruments and equipment which are used by an individual worker and which provide protection from certain harmful agents in his external environment.

The individual protection devices which are used when working with radioactive substances are intended to furnish protection against the entry of radioactive substances into the respiratory and digestive organs of the worker and the direct deposition of such substances on his skin.

Certain devices are used for protection against hard β-radiation (goggles and shields to protect the eyes).

The use of individual devices (for screening) to protect the worker from external γ-radiation is not feasible, since the majority of isotopes emit γ-quanta of very high energy and the fabrication of these devices would require excessively thick protective materials. For example, in order merely to halve the radiation from Co^{60}, goggles fabricated from lead-impregnated glass weighing approximately 3 kg and gloves fabricated from lead-impregnated rubber weighing approximately 17 kg would be required.

Individual protection devices must satisfy not only ordinary hygienic requirements, but also those associated with specific radioactive substances; they must have a very high protective efficiency, must be fabricated from materials which have low coefficients of

adsorption, and must either be easy to clean of radioactive substances or be so simple and inexpensive that they can be discarded when contaminated with these substances.

From the design standpoint, individual protection devices must be as simple as possible, having a minimum number of seams, fasteners, and pockets, and should have a smooth, uniform surface. This design reduces the extent to which protective devices are contaminated when working with radioactive substances and facilitates their cleaning (decontamination).

When fabricating protective devices, it is necessary to observe the principle of relative uniformity of the material, i.e., all materials and components used in fabricating a certain product should have approximately the same chemical stability. This greatly facilitates the selection of a method of decontamination.

Finally, it is desirable to use acid-resistant materials and materials which retain their working characteristics when acted upon by powerful oxidizing and reducing agents for the fabrication of protective devices. This requirement results from the fact that the best methods of contamination for many types and modes of contamination with radioactive substances are those which involve acids and redox reagents.

The individual protection devices used when working with radioactive substances may conditionally be classified into two large groups, basic and supplementary.

The term basic individual protection devices is customarily used to refer to those devices which are systematically used in a given establishment. These include smocks, coveralls, soft shoes, boots, frequently gloves and dust respirators, etc.

Basic protective devices may be subdivided into groups in ac-

cordance with their design and purpose (work clothes, work shoes, gloves, etc.).

Supplementary individual protection devices are those devices which are used under specific circumstances, depending on the radiation conditions and the nature of the work to be performed. This group basically comprises plastic clothing, insulating suits (including pressure suits), helmets, shoe coverings, overboots, boots, etc.

In contrast to basic protective devices, supplementary devices are usually not general-purpose and are intended either to protect certain sections of the body from intensive contamination and spattering with solutions or to protect the respiratory organs from aerosols or vapors and gases. Supplemental devices are consequently classified according to their purpose and the nature of the work in which they are used. Work clothes fabricated from plastic films (as supplemental means of protecting the surface of the body), supplemental shoes (as a means of protecting the basic shoes from contamination), devices for protecting the respiratory organs, etc., are divided into individual groups.

Supplemental individual protection devices are intended for use when the contamination of work areas with radioactive substances is at elevated levels; these devices should have better protective characteristics than basic protection devices. The conditions under which they are designed to function must correspond to the conditions under which they are used and especially to the microclimatic conditions of the work area.

The conditions under which individual protection devices are designed to function is of great importance in the organization of work with radioactive substances. When working, contamination of work shoes and clothing to a certain extent is unavoidable.

We consequently cannot disregard the possibility that radioactive contamination will be brought into clean areas on shoes, work clothes, and other individual protection devices.

As a result of the impossibility of using ordinary protective measures (hermetic sealing, remote control, etc.) in the majority of cases involving repair work, devices and methods for protecting the individual are of prime importance.

During repair work for which a so-called repair zone has been isolated, supplementary individual protection devices are used in addition to the basic devices. In this case, it is necessary to observe a definite procedure for their use.

On entering the repair zone, the worker puts on his supplemental protective devices – shoe coverings, plastic-film work clothes or insulating coveralls, a second pair of gloves, etc. These must be removed when he leaves the repair zone. The possibility of radioactive contamination being carried by his shoes or work clothes is thus eliminated.

In order to reduce the possibility of contaminating neighboring objects and rooms when removing supplemental individual protection devices, it is necessary to decontaminate them first. In order to accomplish this, it is necessary to close off part of the room at the exit from the repair zone with a screen or partition or to set aside temporarily a special room (cleanup room) which has running water, a drain in the floor (for water and cleaning solutions), and the necessary furniture (cupboards and racks for individual protection devices, benches, etc.).

When organizing any new work with radioactive substances, it is necessary to decide on a nomenclature for the individual protection devices required for the work in question. This can be done with a

precision sufficient for practical purposes by using the sets of protective devices recommended by the Sanitary Regulations for work with radioactive substances. These sets contain the work clothing, shoes, and devices to protect the respiratory organs which are necessary in different types of work.

The following set of basic individual protection devices are used in daily laboratory work with small quantities of radioactive substances (work presenting a 3rd-class radiation hazard): coveralls made of bleached moleskin (Article 555, 553) or bleached diagonal (Article 569), a cap of the same material, soft shoes, and gloves (Provisional Technical Specifications of the Main Administration of the Rubber Industry No. UT-995-58) in sizes 8 and 9.

Contamination of underclothing is possible when working with moderate and large quantities of radioactive substances (work of the 1st and 2nd classes).

In this case, everything necessary for a complete change of clothes is contained in the set of basic devices, which then consists of coveralls of bleached moleskin (Article 555, 553) or bleached diagonal (Article 569), a cap of the same material, underclothing of coarse cotton (Article 50, 52, 55), linen (Article 60, 63), or calico (Article 6), undyed knitted socks, boots (Technical Specifications of the Leningrad Sovnarkhoz No. 11016-59) or soft shoes, and gloves (Provisional Technical Specifications of the Main Administration of the Rubber Industry No. UT995-58, sizes 8 and 9).

In addition to the basic devices, in a number of cases it is necessary to use supplemental individual protection devices.

The following set of supplemental individual protection devices can be used for repair and emergency work of the 1st and 2nd radiation hazard classes:

1. An LG-4 (or LG-5) pressure suit;

2. Plastic overboots or rubber boots (Provisional Technical Specifications of the Moscow City Sovnarkhoz No. 3B-6-58).

3. Gloves (Provisional Technical Specifications of the Main Administration of the Rubber Industry No. UT 995-58, sizes 1, 2 and 3).

If the work is of short duration (approximately one hour) and there are no harmful vapors and gases in the air, the concentration of aerosols not exceeding the maximum permissible concentration by a factor of more than 200, it is permissible to use those supplementary protection devices which do not permit entry of air into the space between suit and body instead of the pressure suits and to use the ShB-2 or ShB-1 ("Lepestok") dust respirators to protect the respiratory organs.

The very diverse supplementary protective devices which will be described in the appropriate sections below may be necessary during the course of work. We will now list the most widely employed supplementary individual protection devices employed both for work of the 1st and 2nd classes and for specific work of the 3rd class.

1. Polyvinyl chloride aprons, Specification 80/277.
2. Oversleeves of the same material.
3. Half-smocks of the same material.
4. Semicoveralls of the same material.
5. ShB-1 ("Lepestok") respirators.
6. Organic glass shields to protect the eyes from β-radiation.
7. LIZ-1 pressure helmets.
8. Rubber overshoes.

The conditions under which work with radioactive substances is conducted are exceptionally diverse. The recommended sets are natur-

ally only guidelines and must be changed and supplemented for each specific case, taking into account the actual radiation conditions.

The successful use of individual protection devices depends to a great extent on their maintenance and storage. The general rules for maintaining protective devices are regular dosimetric monitoring (for the opportune detection of contamination by radioactive substances), well-timed decontamination (since the effectiveness of decontamination depends on the level of contamination and on the time for which the radioactive substances have been reacting with the protective devices), careful drying of the devices, and storage in places specially set aside for this purpose (in cupboards, on shelves, etc.).

Rules for the maintenance and storage of various individual protection devices vary widely and depend on the material, design, and areas of use of these devices. Specific maintenance and storage rules will consequently be given below, when describing the specific types of individual protection devices.

COTTON WORK CLOTHES

Cotton fabrics are cheap and widely available materials for the mass production of various fundamental types of basic work clothing and, at the same time, their properties satisfy general hygienic requirements.

The structure of the cotton fiber facilitates the passage of water and vapors through a fabric woven from it, this setting up normal conditions for body temperature regulation for a worker wearing cotton work clothes.

Depending on the structure, thread, and character of their weave, fabrics differ in dust penetrability, capacity to adsorb radioactive contamination when brought into contact with contaminated surfaces, and ability to be cleansed of radioactive substances (decontaminated).

Fabrics with a satin weave (of the moleskin type) have the lowest dust penetrability and the least capacity to adsorb radioactive substances. It is harder to wash radioactive substances from dyed cotton fabrics than from bleached materials. Of the large number of industrially produced cotton fabrics, those which most completely satisfy the requirements for fabrics for outer work clothes, with respect both to protective properties and to physical, mechanical, and physiological characteristics, are bleached moleskin (Article 553, 554, 555) and bleached diagonal (Article 569). It is most expedient to use bleached coarse cotton (Article 50, 52, 55), linen (Article 60, 63), and calico (Article 6) for underclothing. When manufacturing work clothes from cotton fabrics, it is necessary to consider the possibility that they will shrink substantially after laundering (up to 3-4%).

Fig. 20. Moleskin smock.

It is necessary to note that, when cotton clothes come into contact with mineral acids or are decontaminated with acid solutions, they disintegrate and their useful life is sharply reduced. When working under conditions involving the simultaneous action of radioactive substances and aggressive chemical agents on clothing, it is expedient to use work clothing made of synthetic fibers or to wear supplemental clothing made of a plastic film.

Among the design characteristics which differentiate these cotton outer clothes from the work clothes used in other branches of industry is the fact that they contain a minimum number of seams, flaps, fasteners, and pockets, all of which are places where radioactive substances accumulate and hinder decontamination of the entire article.

The following types of cotton work clothes are widely used: smocks, coveralls, jackets and semicoveralls, caps, and socks. When working with small quantities of radioactive substances in the laboratory, smocks of the surgical type, having ties, applied pockets, and elastic at the wrists, are used (Fig. 20).

When working with moderate and large quantities of radioactive substances (work of the 1st and 2nd classes), coveralls and suits are required (Fig. 21). The coveralls have flaps in the front which prevent radioactive contamination from entering under the clothing through the fastening; there is elastic at the wrists and ankles. The suit consists of a jacket and semicoveralls. The jacket fastens in front and has applied pockets. The semicoveralls fasten at the side for ease of dressing.

Caps are used as part of the outfit with all types of work clothes and are intended to cover the entire scalp. The underclothing consists of a shirt with ties in the back and loosely fitting trousers. The wrists of the shirt sleeves and the ankles of the trouser legs are elasticized. Undyed knitted or cotton socks are used when a complete change of clothes is required.

Experience with working with radioactive substances has shown that, with the low levels of contamination which occur under laboratory conditions, cotton work clothing ensures that the body is sufficiently well protected from contamination and is also easy to launder. At high levels of contamination, it is necessary to use supplemental work clothing made from a plastic film.

WORK CLOTHES MADE FROM SYNTHETIC FIBERS

It is possible to produce a fiber whose appearance and properties are just as good as those of a natural fiber, and even better for certain characteristics, from certain types of polymer materials.

The most widely used of the synthetic fibers are caprone, Lavsan, Ftorlon, nitron, perchlorovinyl fibers, etc. The properties of synthetic fibers differ, depending on the nature of the polymer.

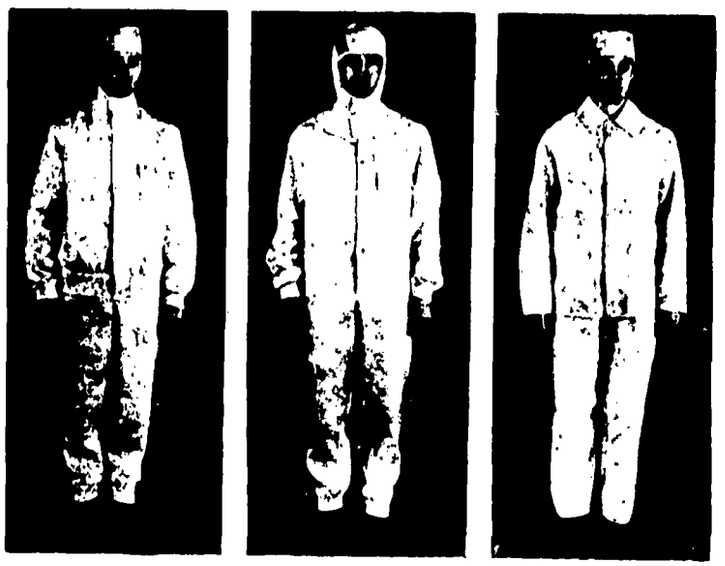

Fig. 21. Work clothing of Lavsan. a) Suit of spun fabric; b) coveralls of spun fabric; c) suit of serge-type fabric.

TABLE 13

Basic Properties of Certain Synthetic and Natural Fibers

1 Название волокна	2 Устойчивость к действию		5 Разрывная длина в км*	6 Температура размягчения в °С
	3 минеральных кислот	4 щелочей		
7 Лавсан	Устойчив 13	Устойчив	40—55	250—265
8 Хлорин	»	»	18—25	60—70
9 Фторлон	»	»	35—40	120
10 Капрон	Мало устойчив 14	»	45—60	210
11 Шерсть	Устойчива	Мало устойчива	11—14	
12 Хлопок	Мало устойчив	Устойчив	27—36	

1) Type of fiber; 2) stability to action; 3) of mineral acids; 4) of alkalis; 5) breaking length in km*; 6) softening temperature in °C; 7) Lavsan; 8) Khlorin; 9) Ftorlon; 10) caprone; 11) wool; 12) cotton; 13) stable; 14) of low stability.

* The length at which a thread breaks under its own weight is called the breaking length; it characterizes the strength of the fiber.

The distinguishing characteristics of the fibers of a number of

polymers are such properties as increased strength and stability to the action of acids, alkalis, etc., this being very important when using synthetic fibers rather than natural fibers in work clothes. Synthetic fibers are hydrophobic, stable to the action of bacteria and microorganisms, and shrink little after being subjected to any process involving water. Caprone and Lavsan are distinguished by their high resistance to wear and their stability to repeated deformation. Table 13 gives data characterizing the basic properties of certain synthetic fibers as compared with those of natural fibers.

TABLE 14

Properties of Fabrics Used for Work Clothes

1	2	3	4		7	8	9
			Прочность полоски 50×100 мм по разрыву по				
№ образца ткани	Название волокна	Вид переплетения	5 основе	6 утку	Вес квадратного метра в г	Толщина ткани в мм	Воздухопроницаемость л/м² · сек
21529	Лавсан 10	Атлас 5/2 11	129	90	215	0,27	202
778	»	Саржа 2/2 12	299	127	403	0,93	23,3
800	»	Двухслойная саржа 2/2 13	342	157	589	1,34	54

1) Number of fabric specimen; 2) fiber; 3) type of weave; 4) tensile strength of 50 x 100 mm strip along; 5) warp; 6) woof; 7) weight of one square meter, in g; 8) thickness of fabric in mm; 9) air penetrability l/m^2-sec; 10) Lavsan; 11) satin; 12) serge; 13) 2-ply serge.

However, the presence of properties such as high strength, increased resistance to wear, and stability to aggressive agents (acids and alkalis), valuable though they be, still do not make it possible to use synthetic fibers for clothes intended for work with radioactive substances.

When working with radioactive substances, the basic, obligatory requirements imposed on materials for work clothes are minimum sorption and an ability to be easily cleansed of radioactive contamination. Just as their other properties, the ability of a synthetic fabric to

be cleansed of radioactive substances depends on the polymer from which its fibers are fabricated.

Fabrics of Lavsan, Ftorlon and Khlorin adsorb radioactive substances poorly and are easily cleansed of them. It is virtually impossible to wash radioactive substances from caprone fabrics and they are consequently unusable as a material for work clothes. Among the easily washable synthetic fabrics, the most acceptable are those of Lavsan, which are distinguished by high mechanical strength and increased thermal stability.

Fabrics of different weights, densities, and thicknesses can be produced from Lavsan, this affecting the washing of radioactive contamination from them.

Table 14 shows certain characteristics of the fabrics recommended for work clothes.

A satin-weave Lavsan fabric is recommended for use in place of cotton materials, while fabrics of the serge type are recommended as replacements for wool materials.

When making work clothes to be used in work involving radioactive substances, the greatest attention must be paid not only to the selection of materials, but also to design, which will ensure protection of the worker's integument, as well as the safety of the work.

The recommended designs for work clothes do not hinder the worker's movements, but make it impossible for the clothes to get caught in the moving parts of machinery. In order to provide maximum protection against the entry of radioactive substances into the space between clothing and skin, the former has a minimum number of seams, fasteners, and pockets. Both the cuffs on the shirt sleeves and trouser legs and the neck of the shirt are made of an elastic Lavsan knit. Figure 21 shows certain recommended designs for work clothes.

Operational experience has shown that Lavsan work clothes have a number of advantages which make it possible to completely replace woolen and cotton materials with this synthetic fabric. It is of higher mechanical strength, is stable to acids and organic solvents, has considerable thermal stability and minimal sorptive properties, and is light as compared to woven clothes. Lavsan clothes are quite as comfortable as cotton clothes.

Lavsan work clothes are now widely used in work involving radioactive substances, mineral acids, alkalis, oxidizing agents, and organic solvents.

WORK CLOTHES MADE OF PLASTIC FILMS

Polymer film materials are used for the manufacture of supplemental individual protection devices. Film materials must be impenetrable to radioactive substances, have a minimal sorptive capacity, and must be easy to cleanse of radioactive contamination deposited on them.

Such a material must be of sufficient mechanical strength, elastic, and long-wearing, these ensuring that individual protection devices fabricated from it will be reliable and comfortable. The material must not have an unpleasant odor, cause irritation of the skin when it comes into contact with it, etc.

Very few industrially produced polymer materials can be used for the manufacture of individual protection devices, since the majority of them adsorb radioactive substances to a high degree and are hard to cleanse of them.

The materials suitable for the fabrication of individual protection devices are specially developed formulas based on polyvinyl chloride of the Specification 80 type, polyethylene films, and fluoroplast films, all of which are easily cleansed of radioactive con-

tamination.

Plastics of Specification 80, 80/277 are easily cleansed of radioactive contamination, characterized by a low degree of water adsorption (0.1-0.3%), and are stable to aggressive agents; they are produced in the form of films 0.25 to 0.7 mm thick.

The tensile strength of these films is 150-180 kg/cm^2 and their tensile elongation is no less than 140%.

In certain cases, additional requirements dictated by specific working conditions are imposed on materials intended for individual protection devices; these include increased resistance to frost, strength, thermal stability, etc.

The strength of polyvinyl chloride films is increased while retaining a thickness of 0.25-0.3 mm by reinforcing them with thin fabrics (netting) woven from synthetic fibers (caprone, Lavsan). In this case, their tensile strength is increased by a factor of 6-10. Polyethylene-based films are distinguished by their high resistance to cold (down to -60°). Films of fluoroplast-26 are of greater thermal stability than polyvinyl chloride films (will withstand a temperature of 100°) and are characterized by increased mechanical strength.

When manufacturing work clothes, the design of the finished product and the production technology are of great importance. The types of work clothes fabricated from film materials which are used in working with radioactive substances are simple in design, easy to put on, and convenient in use; they do not hinder the movements of the individual as he works, have a minimum number of components, and the total length of the seams joining these components is reduced to a minimum.

The thermoplasticity of the material is used when developing a production technology for plastic film work clothes.

Fig. 22. Plastic film work clothes. a) Polyvinyl chloride apron and oversleeves; b) polyvinyl chloride half-smock.

The seams are joined by high-frequency heat sealing, which yields seams which are no less strong than the basic material, have a smooth surface, do not impair the desorption properties of the finished product, and are absolutely airtight.

The following plastic film work clothes are widely used: aprons, oversleeves, semicoveralls, half-smocks, and socks (Fig. 22a). The use of plastic film work clothes ensures that the portions of the body most susceptible to contamination are protected and prolongs the useful life of the basic work clothes.

Oversleeves are used when it is necessary to protect the forearms from contamination with radioactive substances. The oversleeves are fastened above and below by elastic heat-sealed to turned-under areas. There are special apertures under the oversleeves in order to facilitate the circulation of air.

Half-smocks are intended for work in which substantial contamination of the sleeves in the vicinity of the shoulders and of the shirt front is possible. A half-smock has a high collar which completely covers the neck; the back of the garment is short and has ties. The cuffs of the sleeves are elasticized (Fig. 22b).

Semicoveralls are used for brief periods of repair and decontamination work, these protecting the front surface of the basic work clothes and the worker's legs from contamination with radioactive substances and from contact with acids, alkalis, and decontaminating solutions.

The semicoveralls are open to the waist in back in order to improve heat transfer. This garment can be used for no more than two hours because of the difficulty of transferring heat away from the worker's body.

WORK SHOES

Special shoes used as part of a work outfit must satisfy all of the requirements imposed on individual protection devices intended for work involving radioactive substances.

The way in which shoes are used, constantly being in contact with contaminated surfaces and frequently also being exposed to aggressive agents, makes these requirements even more rigid.

The use of leather and rubber work boots and ordinary galoshes is unwise and may be permitted only for work of the 3rd class.

Fig. 23. Special shoes. a) artificial leather boots; b) rubber overboots; c) rubber boots; d) plastic overboots worn over ordinary boots; e) rubber overshoes; f) plastic shoe covering.

The use of leather for manufacturing boots and shoes makes it impossible to decontaminate this footwear, not only because of the high sorptive capacity of leather, but also as a result of the fact that leather footwear loses its shape when subjected to any type of wet (acid) process. The action of the decontaminating solutions renders oilskin boots completely worthless, while galoshes with linings are rapidly contaminated.

The nature of work with radioactive substances requires the designing of special shoes.

The following factors are considered when designing footwear: a) a minimum number of component pieces and a consequent reduction in the number of seams; b) uniformity of the materials used; c) the production of smooth products with no projecting components; d) ease of donning and removal.

Supplemental shoes which are worn when in contaminated areas are used in addition to the basic shoes which are worn directly on the feet. The different types of special shoes are boots with uppers of artificial rubber, rubber boots without linings, rubber overshoes, rubber overboots, plastic overboots, rubber galoshes without linings, latex galoshes, and plastic galoshes; all of these are shown in Fig. 23.

Boots with artificial leather uppers are used when performing ordinary work under conditions which do not involve contact with large quantities of acid and alkaline solutions (Fig. 23a). A comparison of the physical and mechanical properties of boots with artificial leather uppers and those of Russian leather boots is given in Table 15.

According to the data given, work boots designed to satisfy hygienic requirements may be characterized as being very light and elastic (having a rigidity only half that of Russian leather boots) and exhibiting insignificantly decreased heat-protection properties at temperatures approximating room temperature.

High boots (Fig. 23c) are used for certain types of work. These boots are fabricated from a special rubber which ensures a high resistance to acids in addition to excellent desorption properties. The boots are molded from one piece of rubber, cover the entire leg, and are suitable for performing repair work.

The finished product has no projecting components, surface ir-

TABLE 15

Physical and Mechanical Characteristics of Different Types of Footwear

Characteristics	Boots With Artificial Leather Uppers	Russian Leather Boots
Weight of one boot in grams	500	850
Rigidity of boot construction (according to the TsNIKP [Central Scientific Research Institute for the Leather Industry] method), in kilograms	2.3	6.7
Total thermal resistance of product, according to the TsNIKP method, in $m^2 \cdot$hours$\cdot$degrees/kcal	0.170	0.190

regularities, or lining and the pattern of ridges on the sole is designed to provide the best possible flow passage for cleansing solutions.

Several types of supplemental shoes are fabricated from plastics and rubber and are intended to be worn over basic work shoes.

One such type of footwear are rubber overboots, which are fabricated without linings and are easily cleansed of radioactive contamination (Fig. 23b). These overboots reliably protect the feet from possible contact with radioactive substances and aggressive liquids.

Plastic overboots are a special supplemental shoe intended to protect the shoes and feet of the worker from radioactive contamination when performing repair and emergency work. Plastic overboots provide reliable protection for the entire lower leg. In design, these overboots (Fig. 23d) are a molded plastic sole having a rim to which a high film boot top is joined by high-frequency heat sealing. The boots are fabricated from plastic and may easily be cleansed of radioactive contamination.

Shoe coverings are a different type of plastic overboots. These are light plastic boot-like footwear. In design, these shoe coverings (Fig. 23f) are a molded ridged plastic sole 1-1.2 mm thick to which a plastic boot top is joined by high-frequency heat sealing.

The overboots are fastened to the foot with fasteners, straps, or a zipper.

A very convenient type of supplemental shoes are unlined galoshes made of rubber or latex (Fig. 23e).

The great advantage of this type of footwear is the fact that they may be put on and taken off without using one's hands.

Galoshes of one type or another can be recommended for any type of work which does not involve large quantities of spilled liquids.

In work of the 3rd class, where it is possible to wear one's own shoes, it is wise to use supplemental footwear such as galoshes or plastic shoe coverings. Such footwear should be worn both by the personnel of the laboratory and by persons who are visiting it, even for a short time. The supplemental footwear must be removed when leaving the laboratory area.

Work shoes intended for temporary use are of substantial hygienic importance. The use of work shoes, including those which are worn without decontamination until a certain level of contamination is reached or "throwaways" as they are unfortunately called, have become very important, especially since they ensure that neighboring rooms remain uncontaminated and since it is not necessary to organize a special laundry. However, the solution of this problem causes substantial difficulties. Such footwear must be produced by as simple a technology as possible and fabricated from materials which are cheap and easily available. Under these conditions, the use of such shoes can be economically justified, but they must ensure the satisfaction

of an entire set of requirements, albeit less stringent ones, including those for special properties. The manufacture of shoes which fulfill these conditions presents substantial difficulties.

When wearing closed footwear (overboots, boots, etc.), the creation of a suitable microclimate within them is of great hygienic importance. While perspiration is absorbed by the absorbent material of the upper and insole in ordinary shoes, passing through their pores and evaporating, in shoes fabricated from materials which are not permeable to water and vapors, all of the moisture remains inside and this can cause disruption of the temperature regulation and cooling of the feet.

This problem has been solved by the development of socks which are capable of storing the moisture given off by the feet during a 6 – 8 hour period and maintaining a normal temperature regime within the boots, as well as by the development of a special insert in the boot itself which absorbs moisture quite well.

In addition to increasing the service life of footwear, the use of this type of special boots when working with radioactive substances provides a substantial improvement in working conditions when conjoined with the proper organization of the work at hand.

INDIVIDUAL PROTECTION DEVICES FOR THE RESPIRATORY ORGANS

It is known that the so-called respiratory path is one of the principal ways in which radioactive substances can enter the organism. During one work shift, from 4 to 16 m^3 of air passes through the upper respiratory pathways and the lungs, depending on the physical difficulty of the work involved. In this case, a substantial portion of the radioactive substances contained in the inhaled air (in the form of solid or liquid particles in a dispersed aerosol phase, vapors, or gases) are retained by the organism and are excreted from it only with

difficulty.

In the majority of cases, where the air of the work area contains only radioactive aerosols (in concentrations of from one to 200 times the maximum permissible concentration), the use of filter respirators is sufficient to provide effective protection.

The term dust respirator is used to refer to an individual protection device for the respiratory organs which traps in a filter the dispersed aerosol phase from the air which passes through it as a result of the physiological respiratory movements of the individual wearing the device.

In addition to satisfying the special requirements common to all devices for protecting the individual from radioactive contamination, dust respirators for protection from radioactive aerosols must also have other properties.

1. Taking into account possible variations in the concentration of radioactive aerosols in the air of the work area, it is necessary that the respirator reduce the concentration of aerosols by a factor of no less than 1000, i.e., that it have an efficiency of no less than 99.9%.

2. The frequent, often constant use of respirators requires a maximum of ordinary hygienic conveniences: a) minimal resistance to breathing - not more than 3 mm H_2O when the air flow rate is a constant 30 l/min; b) a small dead space; c) low weight; d) no irritation or overheating of the wearer's skin; e) minimal limiting of the field of vision.

Conversely, the use of a respirator which has an unfavorable influence on the physiological functions of the organism is a serious hindrance to work.

Not one of the respirators which are used for protection from non-

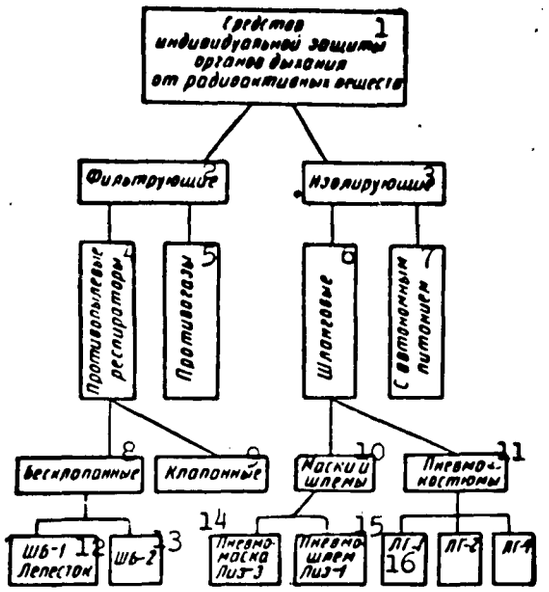

Fig. 24. Classification of individual protection devices for the respiratory organs. 1) Devices for protecting the respiratory organs of the individual from radioactive substances; 2) filtering; 3) isolating; 4) dust respirators; 5) gas masks; 6) with hoses; 7) with self-contained air supply; 8) without valves; 9) with valves; 10) masks and helmets; 11) pressure suits; 12) Lepestok ShB-1; 13) ShB-2; 14) LIZ-3 pressure mask; 15) LIZ-1 pressure helmet; 16) LG.

radioactive aerosols completely satisfies the special requirements and has a sufficiently high efficiency and sufficiently good hygienic characteristics (S.M. Gorodinskiy, 1958). Consequently, respirators which satisfy all of the requirements are used for protection from radioactive aerosols. These respirators were designed around the most effective filtering material currently available, FP. The valveless dust respirators described below do not require decontamination, since they are used only once. One of these respirators ("Lepestok" ShB-1) is widely used for protection both from radioactive aerosols and from

other aerosols which present health hazards.

When protection from joint action of aerosols and gases or from very high aerosol concentrations (which are higher than the maximum permissible concentration by a factor of more than 200) is necessary, gas masks or individual protection devices which provide complete isolation must be used, since respirators do not provide effective protection in such cases. Suits which provide complete isolation must be used when there is a danger of radioactive contamination of the surface of the body.

Special gas masks and insulating devices have now been designed for work with radioactive substances. They are fabricated from special polymer films and other materials which are easily decontaminated. These devices have rather good protective properties. They also completely satisfy the other requirements (S.M. Gorodinskiy, V.L. Shcherbakov, 1957).

Isolating devices for protecting the respiratory organs of the individual may be divided into oxygen (having a self-contained air supply) and hose-connected (having a forced pure air feed from without) devices. The latter are the most widely used and have better physiological and hygienic properties than do oxygen devices, which are used in exceptional cases, where it is impossible to use hose-connected outfits.

The term hose-connected device is used to refer to an individual protection device in which an air-supply system delivers pure air from without in a quantity sufficient for respiration and the generation of a small artificial pressure which prevents contaminated air from entering. Stale air escapes to the outside.

Hose-connected individual protection devices may be divided into pressure suits, pressure helmets, pressure masks, etc., depending on the size of the area of the body to be isolated.

Figure 24 shows the classification of devices for protecting the respiratory organs of the individual from radioactive substances, indicating a number of designs for valveless dust respirators and hose-connected devices.

In this handbook, we will discuss the most widely used of these designs: the "Lepestok" ShB-1 and ShB-2 respirators, the LG-4 pressure suit, and the LIZ-1 pressure helmet.

Valveless Dust Respirators Based on the Filter Material FP

The valveless dust respirators which we are considering have substantial advantages over those with valves. These include:

1) relative simplicity, low weight, and low cost (it is possible to use them only once);

2) it is impossible for unfiltered air to leak in through the orifice of the exhalation valve during inhalation and it is thus possible to design highly efficient respirators.

The filter material FP is a layer of ultrafine organic polymer fibers. There are many types of FP. Most of these types are hydrophobic and have a stable electrostatic charge. FPA is composed of acetylcellulose, is hydrophilic, and it does not have a stable charge. As a result of its hydrophobia, the filter does not swell under the influence of moisture, i.e., its resistance does not increase materially during the course of the work day. The electrostatic charge and thin-fibered structure of the material give it excellent filtering properties. These properties can be compared for various filtering materials, the filtration factor being determined from the formula

$$\alpha = \frac{-\lg K}{\Delta p},$$

where K is the pass factor for a monodispersed aerosol with the most penetrative particle radius (0.15 μ) and Δp is the specific resistance

of the material (N.A. Fuks, 1955, 1961).

In ordinary filter materials (felt, cotton, filter boards, etc.), α is less than 1. In FP, which has a stable electrostatic charge, α is greater than 2.

Under proper storage conditions, the material discharges slowly (and its filtering properties thus deteriorate slowly), over a period of several years. FP discharges rapidly when acted upon by moisture, solutions, electrolytes, and intensive radioactive or x-irradiation.

The electrostatic charge on FP results in its being attracted to the human skin. This property is used in the designs of the "Lepestok" ShB-1 and ShB-2 respirators in order to improve the hermetic seal between the obturator of the half-mask and the face.

FP is stable to acids and alkalies and unstable to oils and a number of organic solvents. It can be used at temperatures of up to 60°C. Special seams ensure that joints between components fabricated from FP are sufficiently airtight.

The resistance of the respirator to respiration P is determined for a one-way air flow at 30 l/min (500 cm^3/sec). For a valveless respirator, this quantity is equal to the resistance of the filter and is determined from the formula

$$p = \frac{\Phi}{S} \cdot \Delta p,$$

where Φ is the flow rate of the air (in cm^3/sec) and S is the area of the filter (in square centimeters).

The working area of the filter in the "Lepestok" ShB-1 and ShB-2 respirators is 250 cm^2 and the formula for these respirators consequently takes the form

$$p_{(ShB-1,\ 2)} = 2 \cdot \Delta p,$$

i.e., a respirator fabricated from FP, which has a specific resistance

of 1.5 ± 0.2 mm H_2O, has a resistance of 3 ± 0.4 mm H_2O (S.N. Shatskiy and P.I. Basmanov, 1957).

The working surface of the filter in the "Lepestok" ShB-1 and ShB-2 respirators is a seamless disk with a radius of 9 cm. When the respirator is put on, the filter assumes an almost hemispherical shape.

Respirators fabricated from FP are stored in cloth wrappers at a temperature not exceeding 50°C and in a clean dry room which is free of vapors containing organic solvents and oils.

The valveless "Lepestok" ShB-1 dust respirator (Fig. 25), designed for one-time use, has recently come to be widely employed and is being produced in large quantities. The respirator is simple in design but complex to manufacture, since the smallest imperfection is grounds for rejection.

The respirator is intended to protect the respiratory organs from radioactive, toxic, and microbic aerosols; under these conditions, a respirator is used for 6 – 7 hours of work and is then disposed of. When the respirator is used for protection from toxic dust or for purposes of asepsis and in other cases where decontamination is unnecessary, the same worker can use it repeatedly for up to 5 work days.

The respirator weighs approximately 10 g; for highly dispersed aerosols, its efficiency is 99.9% and its resistance to breathing is approximately 3 mm H_2O.

The respirators are stored unfolded. Before the respirator is used, the ends of the rubber cord are stretched to the necessary length and tied. The respirator is used as a half-mask (Fig. 25).

In putting the respirator on, it is first fitted about the chin and its upper edge is then placed on the bridge of the nose, the forming strips are pressed into position, and the straps are tied without being stretched unduly tight (Fig. 26). The obturator adheres closely

Fig. 25. The "Lepestok" ShB-1 valveless dust respirator ready for use (the ends of the rubber cord have still not been cut). 1) Cover; 2) rubber cord; 3) forming strip; 4) stiffener; 5) straps.

Fig. 26. "Lepestok" ShB-1 respirator as worn.

to the face as a result of the tension on the rubber and the electrostatic properties of FP.

The low resistance to breathing, light weight, and other properties of the "Lepestok" ShB-1 respirator make it possible to use it daily, for the entire work day. After a week, a worker performing work of moderate difficulty, and frequently even one performing heavy physical labor, has completely adapted to the respirator.

The time required for personnel to adapt to working with the "Lepestok" ShB-1 respirator is sharply reduced, to several days or even hours, when respirators with a reduced resistance (1 – 1.5 mm H_2O) fabricated from FP materials, which have a very high filtration factor, are used.

Long experience in the use of "Lepestok" ShB-1 respirators has shown that it is possible to use them for protection from various radioactive aerosols. For example, they are used for protection from the daughter products of radon, which produce the major portion of the total activity of the latter. A highly efficient respirator traps not

only aerosol particles, but also the daughter products of radon (principally RaA) in the atomic state.

The ShB-2 valveless dust respirator prevents the entry of health-endangering aerosols into the human organism through the respiratory organs and protects the entire surface of the face, head, and neck from contamination. The ShB-2 respirator is intended for protection from the microbic agents of dangerous infectious diseases, radioactive aerosols, and other aerosols of any dispersion (S.N. Shatskiy, 1959). The respirator is used for one day; however, when working with microbic and unstable toxic contaminants, it can be used for up to five work days if it can be completely decontaminated or disinfected without being subjected to the action of liquids and high temperatures (on condition that the respirator remains intact after each cleaning).

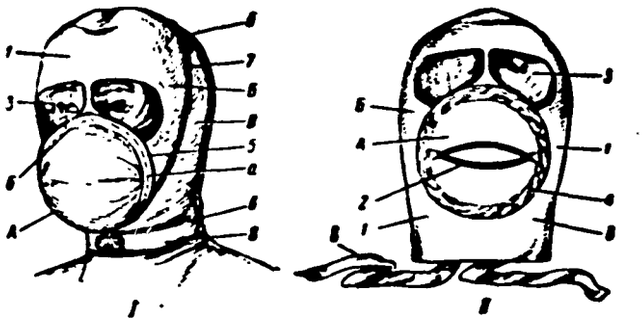

Fig. 27. Design of the ShB-2 respirator. I) Overall view of respirator as worn; II) inside view; A) Region of basic filter; B) region of first compensating filter; C) region of second compensating filter; a) Facial obturator; b) median obturator; c) cervical obturator; 1) covering; 2) stiffener; 3) view port; 4) lining of facial obturator; 5) edge of rubber cord; 6) forming strip; 7) rubber cord; 8) strap.

The design of the ShB-2 respirator is shown in schematic form in Fig. 27.

The design of this respirator includes three successive obturators

(the first of which, the facial obturator, is reinforced by a lining of FP) and a system of compensating filters. The latter successively purify the air which passes through defects in the hermetic seals of the obturators. This system almost completely prevents inleakage of unfiltered air.

If the coefficient of inleakage for each obturator is 0.01, only 0.0001% of the particles of the dispersed aerosol phase enter the region of the basic filter as a result of defects in the hermetic sealing of the obturators, this being less than the pass factor of FPT-15 - 1.5, of which the respirator is fabricated, by a factor of approximately 100.

The efficiency of the ShB-2 respirator is thus equal to the efficiency of the filter material from which it is fabricated, i.e., is not less than 99.99%. The respirator weighs approximately 60 g and its resistance to breathing is approximately 3 mm H_2O.

ShB-2 respirators are wrapped in airtight covers of a waterproof plastic film which are removed before use.

It is possible to work continuously for the entire work day while wearing the ShB-2 respirator. As far as the respiratory functions are concerned, the physiological data for this respirator are similar to those for the "Lepestok" ShB-1. In constrast to the ShB-1, the ShB-2 respirator somewhat limits the field of vision and, during the hot periods of the year, can cause some overheating during especially heavy physical labor.

In addition to the basic designs described above, there are various special modifications of the "Lepestok" ShB-1 respirator, these being intended to trap certain gaseous substances in addition to aerosol particles.

Respirators designed for prolonged use and having removable fil-

ters based on FP are also employed.

PROTECTION DEVICES WHICH ISOLATE THE WORKER

a b

Fig. 28. The LG-4 pressure suit. a) Overall view; b) working in the LG-4 pressure suit.

Protection devices which isolate the worker are supplemental protection devices and are intended for use in repair, emergency, and decontamination work, when the contamination of the atmosphere with radioactive substances, including gaseous substances, is at high levels.

The hose-connected isolating devices for protecting the respiratory organs now used in work with radioactive substances are of two types, Type LG pressure suits and pressure helmets.

The term pressure suit is used to refer to a hose-connected isolating suit in which air is supplied to the area within the suit. There are several modifications of the Type LG pressure suit. The most highly perfected of these is now the LG-4 pressure suit (LG-5). This suit is a loose-fitting coverall with a plastic helmet hermetically sealed to it (an external view of the LG-4 pressure suit is shown in Fig. 28 a

and b).

The pressure suit is fabricated from a polyvinyl chloride film 0.3 mm thick reinforced with caprone in order to increase its resistance to tearing or of a thicker (0.4 mm) frostproof polyvinyl chloride film (Specification 80/277). The view port and the tube through which air is supplied to the suit are fabricated from organic glass. These materials are easily decontaminated by the use of methods involving acids and redox reagents.

There is a tucked-under "manhole" in the front of the coveralls which makes it possible to put the LG-4 pressure suit on rapidly, without outside aid.

All the components of the pressure suit are joined by high-frequency heat sealing.

The LG-4 pressure suit operates on the following principle: pure air is supplied through a rubber hose and a soft plastic air inlet in the upper portion of the helmet. The air stream strikes the view port, passes downward through the space within the suit, and is discharged through valves in the lower portion of the trousers of the coveralls.

When the air flow rate is sufficient (200 - 400 l/min), the view port does not sweat and normal body temperature regulation conditions are ensured for the worker in the pressure suit. At the same time, a slight artificial air pressure in the space within the suit prevents contaminated air from the outside from penetrating beneath the suit, even when it is mechanically damaged.

The LG-4 pressure suit ensures protection to the worker wearing it when the concentration of radioactive aerosols in the surrounding air exceeds the maximum permissible concentration by a factor of no more than 10,000 and when the concentration of radioactive vapors and gases exceeds the maximum permissible concentration by a factor of no more

than 1000. The pressure suit naturally does not protect the worker from external streams of γ-radiation and neutrons and from high-energy β-radiation.

Working in a pressure suit prevents the possibility of radioactive contamination of basic work clothes and, even more important, of the integument as a result of direct contact with equipment while working. Basic work clothes and the skin (especially the hands) can be contaminated when the pressure suit is removed, if the latter is not first decontaminated with sufficient care.

The material from which the pressure suit is fabricated permits it to be used at air temperatures of from −10 to +50°. Physiological and hygienic investigations of functional changes in the organism of workers wearing the LG-4 pressure suit have shown that it is permissible to work in this suit for 3 – 4 hours when the temperature of the surrounding air is 30° or less (on condition that the air supply to the suit is normal) and for 1-1/2 hours at a temperature of 40°. At higher temperatures, these suits must be used in conjunction with a cooling covering, a KKhO. The KKhO (cotton cooling coveralls) is worn over the isolating suit and is periodically (as the worker in the suit requires it) drenched with cold water.

The heat capacity of water and its evaporation from the surface of the suit combine to cause a flow of excess heat from the space within the suit. Using the pressure suit in this manner makes it possible to extend the time for which a worker may remain in it to more than 2 hours when the temperature of the surrounding air is 60° or less.

It is wise to use the LG-4 suit as part of an outfit which includes plastic overboots (or rubber boots) and two pairs of gloves (the cuffs of the inner pair of gloves are inserted under the rubber sleeves). This combination of supplemental protection devices makes it

possible to decontaminate them first under a shower in the clean-up room while the worker is still wearing them.

Preliminary decontamination of the protection devices reduces the possibility that the worker will be contaminated while undressing and, to a substantial degree, facilitates decontamination in the special laundry, since all unfixed radioactivity is disposed of immediately after the work is completed.

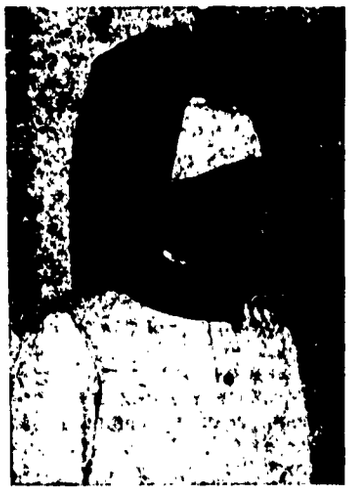

Fig. 29. The LIZ-1 pressure helmet.

Basic decontamination of the pressure suits is carried out in special laundries, in special washing machines or in tubs with bubblers, in accordance with standard practices for handling plastic clothing.

The pressure suits which have been cleansed of radioactive contamination are stored in the medical services areas or in the clean-up rooms and are either hung up or (after careful drying) are put on shelves.

The temperature at which pressure suits may be stored and transported depends on the specifications for the material from which they are fabricated, being no less than -15° for Specifications 80 AM or 80/277 and no less than $+5^{\circ}$ for Specification 80.

In order to ensure proper conditions for the use of pressure suits, establishments which work with radioactive substances should be equipped with permanent high-pressure lines for supplying air to the suits and with shower stalls for preliminary decontamination of the suits. The use of portable fans and preliminary decontamination of the pressure suits at the work site itself with water from a hose is permissible only in exceptional cases, since palliative measures do not com-

pletely prevent contamination of the air supplied to the suit and do not set up the conditions requisite to careful preliminary decontamination.

When planning the air-supply lines, special attention must be paid to the air pressure drops in different sections of the system. In order to ensure normal air feed to the suit through a smooth rubber hose with a diameter of 20 mm and a length of 20 m, it is necessary to set up a pressure of the order of 500 mm H_2O at the inlet to the hose. Such a pressure can be furnished only by special high-pressure fans (such as the RMK-2 and RMK-3).

As actual work experience has shown, the degree of success with which pressure suits are employed is determined principally by the conditions under which the suits and clean-up rooms are used. The design of the LG-4 pressure suit has been used as the basis for designs for certain other pressure suits intended for specific types of repair or emergency work (the LG-5 pressure suit, etc.).

Pressure helmets are used far less often than are pressure suits. Pressure helmets are advantageously used in those cases where contamination of the basic work clothes is unlikely, but it is necessary to protect the respiratory organs. For example, the simplicity of its design makes it very convenient to use a pressure helmet when going into a repair zone for a short time or when inspecting equipment in contaminated rooms.

The LIZ-1 pressure helmet is the most convenient from the design standpoint. The LIZ-1 pressure helmet is fabricated from a thickened polyvinyl chloride film (0.7 mm) and organic glass (Fig. 29). The components of the helmet are joined by high-frequency heat sealing. Air is supplied to the helmet in the same fashion as for the LG-4 pressure suit.

The basic decontamination, storage, and transportation of pressure helmets are handled in a manner similar to the decontamination, storage, and transportation of pressure suits (pressure helmets are not subjected to preliminary decontamination). In addition to the LIZ-1 pressure helmet, there are a number of other special-purpose pressure helmet and pressure mask designs; these include the LIZ-3 pressure mask, which is used in mining.

The use of hoseless isolating devices for protecting the respiratory organs (devices of the oxygen type) when working with radioactive substances is very limited.

The design complexity of such protection devices and the consequent impossibility of decontaminating them when high levels of contamination are reached makes it difficult to use them repeatedly, this being extremely disadvantageous economically, since the cost of oxygen devices is rather high.

Hoseless isolating protection devices should be used only in those cases where it is virtually impossible to use pressure suits and pressure helmets.

GLOVES

Gloves are used to protect the hands when working with radioactive substances. Of the polymer materials, rubber compositions are the most advantageous, satisfying the requirements of elasticity and strength imposed on gloves. Rubber compositions based on natural and synthetic rubbers have come into wide use. Gloves fabricated from polyvinyl chloride and polymers containing chlorine are now also used for certain types of work.

It is occasionally impossible to use ordinary rubber gloves when working with radioactive substances, since the material from which they are fabricated does not withstand prolonged exposure to aggressive

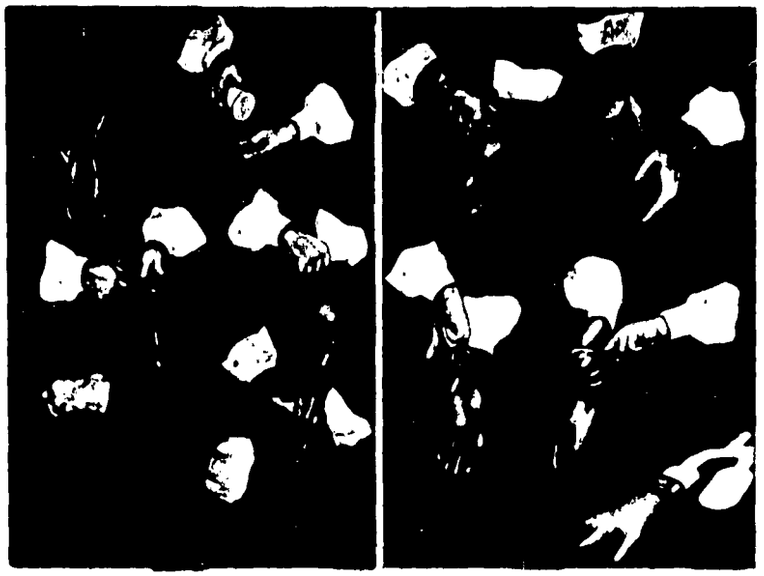

Fig. 30. Method for putting on (a) and removing (b) gloves.

agents and is permeable to certain radioactive substances. Gloves fabricated from specially developed Nayrit latex are consequently used when working with radioactive substances. This material has good technological properties, is stable to the action of aggressive agents, and scatters α-active substances to only a small extent.

Gloves are fabricated in several forms, depending on the nature of the work to be performed. For precise laboratory work, the fingers must retain their sensitivity and thin-walled gloves, so-called surgical gloves, are used. For gross work, industrial gloves are used. Gloves with long gauntlets are used for working in boxes.

Special attention must be paid to the correct use of gloves; carelessness in changing gloves can cause intense contamination of their inner surface and consequently of the hands. Figure 30 shows the correct methods for putting on and removing gloves.

In order to facilitate putting gloves on, the hands are first

dusted with talcum powder; the worker then puts the gloves on carefully, turning up the cuffs and adjusting the gloves on his fingers.

When putting on and removing gloves, care must be taken that the bare fingers do not touch the contaminated outer surface. The gloves are removed with the same care used to put them on. Before the gloves are removed, they are carefully washed and wiped with filter paper; they are then stretched on wooden blocks and dried. It is desirable to have special cabinets in which to store gloves.

Section 4

DOSIMETRIC AND MEDICAL MONITORING

Chapter 1

DOSIMETRIC MONITORING

Clear organization and systematic performance of dosimetric monitoring of the safety of working conditions and the purity of the external environment are required to safeguard the health of persons working with sources of ionizing radiations.

Dosimetric monitoring is concerned not only with dosimetry itself, but also with radiometry of ionizing radiations and evaluation of radiation protection, the effectiveness of decontamination, the trapping of radioactive gases and aerosols, the purification of waste liquids, etc.

Dosimetric monitoring must be conjoined with general medical monitoring, in order that all factors involved in the action of the external environment on man may be completely considered and evaluated. For example, in order to evaluate working conditions for work with elementary particle accelerators (the betatron, the synchrotron, the cyclotron, etc.), it is necessary to determine the content of ozone and the oxides of nitrogen in the air, the intensity of long-wave radiation, and the noise level, in addition to measuring the neutron and γ-radiation fluxes.

Dosimetric monitoring must be systematically conducted in the basic and auxiliary rooms and the rooms adjacent to these and at work sites at which personnel are continuously or temporarily present. In all cases, preliminary dosimetric measurements which take into account all possible types of exposure must be made before beginning work with

sources of ionizing radiation. The work time and individual protection devices to be used are determined beforehand. All adjustment, repair, and emergency work must be performed under the supervision of workers from the dosimetric department.

Depending on the nature of the work and the sources of radiation, the ionizing radiation dose is measured and the content of radioactive gases and aerosols in the air is determined, permanent installations and portable dosimeters being used in this case. At the same time, the degree to which the equipment, furniture, building components, and the workers' clothing and integument are contaminated with radioactive substances is determined. Dosimetric monitoring of the integument must be conducted during work, after washing, before eating, and before leaving work.

The nature of the dosimetric monitoring, the number of analyses and measurements necessary, and the choice of equipment to be used are determined by the problems presented, the volume of work, and the conditions under which this work is performed.

If the work is conducted with shielded sources (as in γ-defectoscopy), dosimetric monitoring is limited to measurement of the γ-radiation level and determination of the integral γ-radiation dose received by the personnel. When working with unshielded radioactive substances such as luminous dyes, the γ-radiation dose in the workroom, the concentration of radioactive aerosols (radium, radon decay products) and gases (radon) in the air, the level of contamination of the integument, work clothes, the floor, equipment, etc. are monitored.

In all instances, it is necessary to know the toxic radioactive substances involved in the work; the nature of the work and the activity level of the preparations at the work sites must also be known. It is also necessary to establish the type of radiation, its energy,

the half-life of the radioactive substances, and the aggregate state in which they enter the air (gaseous, vaporous, or in the form of aerosols). It is necessary to pinpoint the possible sources of radioactive substances and to determine the conditions which obtain for contamination of the integument, clothing, and equipment and building surfaces. The necessity for taking prophylactic measures must be considered and substantiated.

Proceeding from the nature of the work and being guided by the purposes of the examination, a concrete plan indicating the type and number of measurements and analyses necessary is drawn up, the site chosen for the investigation is established, etc. The plan for effecting the examination is drawn up by a physician specializing in industrial hygiene and by a specialist in physical dosimetry; chemists and specialists in ventilation are added when necessary.

In addition to the planned measurements, it becomes necessary to make a number of individual measurements in conjunction with repair and emergency work or work with radioactivity levels greater than those provided for, etc.

Daily dosimetric monitoring of working conditions should be carried out with the resources and facilities of the institutions in which work with radioactive substances is being conducted, while periodic monitoring should be conducted by public health and epidemiological stations. Dosimetric monitoring can be both general and individual.

GENERAL DOSIMETRIC MONITORING

General dosimetric monitoring may be conducted with both fixed and portable devices.

General dosimetric monitoring with fixed devices refers to that monitoring system in which the sensors of the dosimetric instruments

are always located at points which require measurement of one or more types of radiation (γ-radiation, neutron fluxes radioactive gases and aerosols). Various fixed dosimetric instruments are used for this purpose, it being possible to install the measuring unit at a considerable distance from the place where the sensor is located. As a rule, such instruments are equipped with signalling devices which operate when the maximum permissible radiation levels are exceeded.

Dosimetric monitoring with fixed instruments must be carried out at those places where working conditions require continuous or daily measurement of radiation. This is especially true of rooms in which work with radioactive substances is actually conducted and in which operating personnel are always present, as well of rooms in which sharp changes in the irradiation dose power are possible. This latter class includes rooms containing equipment for servicing a reactor or accelerator, as well as rooms containing shielded cabinets, storage areas which operating personnel enter daily, etc. Dosimetric measurements in such rooms must be made systematically, following a predetermined schedule based on the work schedule.

Depending on the nature of the work and the number of points which must be monitored, there are two versions of the fixed dosimetric instrument setup which can be used. In the first variant, the dosimeter sensor and the measuring unit are installed together, a health physicist reading the instrument on his rounds. The personnel working in the area keep track of the instrument readings at all other times. When the maximum permissible radiation levels are exceeded, the personnel take the measures specified in the instructions for safety practices.

In the second variant, the dosimeter sensors are installed at the measurement sites, while the measuring units and control levers are located in the same place; the latter may be either on a panel in

the office of the dosimetric department or on the control panel in the control room. This ensures convenience of repair and control and prevents contamination of the main unit of the instrument. In general dosimetric monitoring, the dosimeter sensors can be spaced around the walls of the room, this making it possible to evaluate the dose power at any point in the room. In order to increase the safety of the workers, a number of dosimetric instruments are equipped with signal devices. These are installed in front of the entrance to the workroom and are duplicated on the general control panel.

The signals usually make use of light (single) or light and sound (grouped).

In a number of instances, it is wise to install a selector in parallel with the signalling system, so that the health physicist can give his orders from the panel, on the basis of all data on the necessity of halting work or taking other measures to eliminate the causes of the increased radiation level.

Portable dosimetric instruments are most frequently used when radioactive substances are involved. These devices make it possible to monitor the external radiation fluxes.

The dosimetric department should have a chart showing the points at which the fixed dosimetric instruments are making their measurements. The readings of the instruments are recorded in a special record book which shows the date, time, and dose power at the point in question. Ever wider use is now being made of selfrecording instruments, which make it possible to obtain a complete picture of the radiation in a certain room during the course of the day as a function of the operations performed and the working conditions.

The dosimetric monitoring system described above is used in laboratories, in atomic power stations, and for reactors.

INDIVIDUAL DOSIMETRIC MONITORING

Individual or, as they are occasionally called, pocket dosimeters which are affixed to the worker's clothing are used for individual dosimetric monitoring. The location of the dosimeters depends on the nature of the work to be performed. In certain cases, they are located in the thoracic area, while in others they are placed at the worker's abdomen or head or on other parts of his body. In cases where intense irradiation of the feet or hands is anticipated, the worker must be furnished with two dosimeters, one of which should be placed on a hand or foot and the other in the thoracic or abdominal region, so that both the local and whole-body radiation doses are measured.

The methods of individual γ-ray dosimetry include the IFK (individual photographic monitoring) method based on the use of photographic films, the IDK (individual dosimetric monitoring) method, which uses ionization chambers, and the ILK (individual luminescence monitoring) method, which uses scintillating phosphors. The IFK and ILK methods are also used for monitoring thermal neutrons and β-particle fluxes.

The greatest advantage of individual photographic monitoring is the fact that continuous recording of the irradiation of personnel is possible. Other advantages of this method are the ease with which it may be documented and the relatively high mechanical strength and low cost of the dosimeters. The IFK method is used in the γ-radiation energy ranges covering 0.4 to 3 Mev without lead shields and 0.1 to 3 Mev with lead shields. The dose measurement range extends from 0.06 to 3 r for films of the "Roentgen" XX type and from 0.5 to 15 r for films of the "Roentgen" X type. The measurement error is $\pm$ 30%. When recording the slow neutron irradiation dose, the IFKN method makes it possible to record from 0.002 to 0.3 reb on film of the "Roentgen" X type and from 0.001 to 0.1 reb on film of the "Agfa" type. The draw-

backs of this method include the impossibility of obtaining results rapidly because of a long film development time, a consistently high consumption of photographic materials, the impossibility of checking the quality of the film beforehand, etc.

The merits of the IDK method are a sensitivity somewhat higher than that of the IFK method (a measurement range of 0.02 – 50 r) and an accuracy of ± 10%. The drawbacks of this method include an increased leakage current in portions of the chamber, which limits the measurement time. The chambers are used for energy ranges of from 0.1 to 2 Mev if they are fabricated from plastic and from 0.2 to 2 Mev if they are fabricated from aluminum. Several types of dosimeters for individual monitoring have now come into use. The KID-1 individual dosimetric monitoring outfit consists of a panel containing a charge-measuring device and 20 or 100 double-condenser ionization chambers. The dose measurement range extends from 0.02 to 2 r; power is supplied from the local a.c. lines.

The DK-0.2 direct-reading pocket dosimeter is a small electroscope with a scale graduated in milliroentgens. The measurement range is 0 – 200 mr. A ZD-3 battery charger is used to charge the device. A battery power supply is used.

The advantage of the ILK method is its wide dose measurement range, from 0.01 to 2000 r. ILK cassettes are used for the energy range which extends from 0.1 to 3 Mev. The ILK method also makes it possible to record the slow neutron irradiation dose, starting at a lower limit of 0.01 reb.

Different individual monitoring methods give different readings, these depending on the working conditions (the presence of hard γ-radiation, its spectral composition, the presence of fast and slow neutrons, etc.). All of the errors in the various methods (the leakage

current in the KID chambers, accidental exposure of the film in the IFK or ILK cassettes, the presence of a substantial amount of soft γ-radiation or partial penetration of hard β-radiation into the cassettes and chambers) always causes an elevated reading.

When there is substantial scattering which exceeds the measurement errors of the various individual monitoring methods used, it is necessary to determine the cause of such scattering in each individual case and eliminate it.

The individual dosimetric monitoring data must be entered in record books or on standard charts compiled for each worker. It is very important to record the doses received by coworkers, since such records furnish valuable information to medical workers carrying out prophylactic measures, as well as important data for medical study.

It is desirable that the total doses received by each coworker be compiled for the monitoring period at the end of each quarter and each year. When workers are transferred to another enterprise which has dosimetric monitoring, their personnel record books should be sent to the new work place.

One of the essential areas of dosimetric monitoring is the determination of the total irradiation dose received by each worker during both continuous and temporary work with sources of ionizing radiations.

When the worker is subjected to the combined action of different types of ionizing radiations and when there is a possibility of both external and internal irradiation, it is necessary to consider each type of radiation individually and to sum them after the appropriate calculations in order to evaluate the dose.

BASIC INSTRUMENTS FOR RECORDING RADIATION

Equipment designed for the recording and measurement of all types of radiation is called radiometric equipment. The devices used for the

actual evaluation of the radiation dose are called dosimeters.

Different types of sensors are used to measure different types of radiation, this resulting from the fact that different recording methods are used for individual types of radiation.

Ionization chambers whose scales are graduated in microroentgens per second are thus as a rule used for measuring streams of electromagnetic radiation.

Thin-wall gas discharge counter tubes and end-window counters are used to record hard and soft β-radiation fluxes.

Scintillation sensors have recently come into wide use in the dosimetry of ionizing radiations. The operation of scintillation detectors is based on the use of the luminescence which develops when ionizing particles interact with the atoms of special crystals.

All dosimetric equipment consists of the following basic components: a sensor, a measuring instrument, a power supply, and an amplifier. Apparatus of this type may be either portable or fixed. Special requirements are imposed on portable instruments; these devices must be of light weight and small size and must react only slightly to changes in temperature, humidity, and atmospheric pressure. The instruments must be simple to repair and easy to decontaminate.

Measurement of X- and γ-radiation. Various dosimeters, which may be either portable or fixed, are used to determine the x- and γ-radiation doses at work sites, these measurements being used to monitor the reliability of protective measures. In principle, all dosimetric equipment for measuring x-radiation consists of the following basic units: a sensor in the form of an ionization chamber, a measuring instrument, a power supply, and a d.c. amplifier. Dosimeters which use power supplied from the local d.c. lines often consist of several units connected with cables. Instruments supplied by batteries are made compactly,

without separable connections, and are basically portable devices.

Depending on their purpose and the energy of the radiation involved, dosimetric equipment may be subdivided into dosimeters for measuring x-radiation in radiation therapy (the RM-1-M medical roentgenometer and the Type MRM 1-M microroentgenometer) and instruments for recording and measuring large (US-DD) and small γ-radiation dose powers (PMR-1, DKZ, "Cactus," RK-01, DP-11-B) in general dosimetric monitoring under laboratory and industrial conditions.

The RM-1-M medical roentgenometer is used for the dosimetry of x- and γ-radiation with an energy of 0.6 – 1.5 Mev in order to determine depth doses and for intracavitary measurements; it measures 0 – 50,000 r. The maximum external dose for intracavitary measurement is 450 r; the dose is determined from a graduated graph on the RM-1-M rating plate.

Power is supplied to the instrument from the local a.c. lines; the measurement error does not exceed ± 10% of the maximum value of each scale. The instrument is equipped with a signalling device. In order that the scale may be read correctly, it is necessary to calibrate this type of roentgenometer either on a x-ray apparatus where with the aid of master γ-radiation sources.

The Type PMR-1 portable microroentgenometer is suitable for measuring comparatively low dose powers of x- and γ-radiation, in the energy range extending from 0.2 to 2 Mev. The limits of measurement lie at 0.5 and 5000 μr/sec. The instrument has a battery power supply. The sensing element of the instrument is a 1 liter ionization chamber mounted in the lower portion of its aluminum housing. A microammeter graduated in microroentgens per second is mounted on the cover of the instrument. The Type DKZ protective monitoring dosimeter is a roentgenometer of the same type. Its limit of measurement is substantially lower, being 50 μr/sec.

The dose power is determined from a graduated curve affixed to the instrument. The two types of instruments described, the PMR-1 and the DK, are portable.

The "Cactus" fixed dosimeter is used to measure the dose power of hard γ-radiation and for signalling when a given threshold dose power is exceeded in laboratory areas. The range of energies measured extends from 0.2 to 2 Mev; its total range is from 0 to $2 \cdot 10^4$ μr/sec. When the conditions shown on the rating plate are maintained, the instrument error is small, being $\pm$ 5% of the maximum value of each scale.

A number of portable radiometers with scintillation sensors are being industrially produced for the determination of low γ-radiation dose powers. The Svet-3 (SRP-1a) and SG-42 radiometers are of this type. The measurement limits lie at 0 and 1000 μr/sec.

Neutron Dosimetry. Depending on the energy of the neutrons, neutron dosimetry may be subdivided into three classifications:

a) thermal neutron dosimetry ($E_n \simeq 0.025$ ev);

b) "intermediate" neutron dosimetry (1 ev$<E_n<$0.1 Mev);

c) fast neutron dosimetry (E_n = 0.5 – 10 Mev).

At the present time, thermal neutron dosimetry is the most highly developed of these. Various methods are used for thermal neutron dosimetry. Thus, the radioactive tracer method is widely used for research purposes in work involving the study of depth doses in phantoms. These methods are also used for making cartograms of thermal neutron fields when large irradiation doses are involved.

Proportional BF_3 sensors with a.c. or battery power supplies are used in certain instruments ("Ether," KPN-2, etc.). Instruments of this type are calibrated in thermal neutron fields with the aid of radioactive tracers and make it possible to make measurements in the range extending from 0.01 to 100 maximum permissible thermal neutron

fluxes against a background of γ-radiation of approximately 100 μr/sec.

So-called fission chambers can also be used for the dosimetry of thermal neutron fluxes; a substance fissile to thermal neutrons is deposited on the walls of the chamber. This type of instrument is far less sensitive than proportional counters and may consequently be used only for measuring high thermal neutron fluxes.

So-called thimble chambers are most suitable for absolute measurements of fast neutron fluxes (particularly for calibrating instruments). However, as a result of their low sensitivity, chambers of this type are used in experiments where the fast neutron fluxes exceed the maximum permissible fluxes by factors of thousands and hundreds of thousands.

The Type RUS-4 general-purpose scintillation radiometer has recently come into wide use in the dosimetry of neutron fluxes. The instrument is designed to be compact and is portable, having both a storage battery and a line cord supply.

The RUS-4 radiometer is equipped with a set of interchangeable sensors for recording all types of radiation, as well as for measuring thermal and fast neutron fluxes.

The operation of the scintillation detectors is based on the use of the luminescence which develops when ionizing particles interact with the atoms of certain media. Detectors fabricated from a mixture of B^{10} or Li^{6} and a highly efficient scintillator such as zinc sulfide (ZnS) introduced into a carrier are required for the dosimetry of thermal neutrons; fast neutrons are slowed down to thermal velocities in a paraffin block and are measured by this method.

Measurement of β-radiation. It frequently becomes necessary to determine the absolute activity of a β-radiator, i.e., the number of β-decays which occur per unit time in the preparation being measured. As a rule, end-window counters and special counter devices of the B-2, PS-10,000,

PK-1000, etc. types are used for such measurements. The B-2 counter, which is widely used in the laboratory, consists of two units: the BGS-2, which serves to fix the sensors and connect them to the electrical system of the counter, and the VSP, which consists of a high-voltage rectifier and a scaling device equipped with an electromechanical counter and a timer. A protective cell fabricated from lead is usually used to shield the counter from external sources of radioactive radiation. When converting from the measured number of impulses to the number of β-decays in the preparations when making measurements with the aid of counters, it is necessary to introduce special corrections for self-absorption, backscattering, the number of decays, the measurement geometry, etc.

The "Tiss" general-purpose radiometer is now widely used for measuring contamination of the surfaces of the hands or of clothing. This instrument is equipped with three types of sensors which make it possible to record α-(E>3 Mev) and β-(E>0.6 Mev)-radiation. In this case, the γ-radiation dose power should be no greater than 3 μr/sec. When this level is exceeded, the instrument readings are distorted. The instrument measures the contamination level in relative units, impulses per minute. The maximum measurement range reaches 100,000 impulses/min. If the type and energy of the radiation are known, the scale readings can be converted into decays/min with the aid of specimen sources (standards), this making it possible to measure levels of contamination in absolute units. This device also makes it possible to obtain a signal which indicates that the contamination has exceeded a permissible level established by the operator.

The Type "Beam-A" radiometer is another type of instrument which makes a qualitative and quantative differential evaluation of soft and hard β- and γ-radiation. This instrument is equipped with a sound sig-

nalling system. Differentiating screens are added to the set of sensors, so that separate records of β- and γ-radiation may be made.

Measurement of Radioactive Aerosols. It is quite difficult to measure the concentrations of radioactive aerosols in the air when these concentrations are low. In order to evaluate such concentrations, the aerosol particles must be collected from a large volume of air and a very sensitive radiometric apparatus must be used.

Air samples for evaluating the concentrations of radioactive aerosols may be taken with the aid of membranous filters (fabricated from materials of Types FP, FPA, and FPP and from filter paper), liquid filters, and certain other devices.

Each device for taking air samples, treated separately, consists of a filter support and filter, an instrument for measuring the rate at which air is pumped through the filter, a blower, and a counter for determining the absolute activity of the aerosols.

The most frequently used method involves precipitation of the active dust on membranous filters. It is convenient to use a filter fabricated from a Type FP-15 material, which has a very low pass factor and a relatively low resistance, as the membranous filter. Radiometric devices such as the B-2 radiometer with an end-window counter (for β-radiation) or a scintillation attachment for the B-2 radiometer (for α-radiation) are used to determine the absolute activity of the aerosols contained in the filter.

The concentration of active aerosols q may be equated with the counting rate which the filter excites in the counter in the following fashion:

$$q = \frac{N}{2{,}2 \cdot 10^{12} \eta k v t}.$$

where q is the concentration of active aerosols in curies/l, N is the

counting rate of the filter activity in impulses/min, $\underline{k}$ is the overall correction factor, which comprises all of the corrections introduced, $\underline{v}$ is the rate at which air is pumped in l/min, $\underline{t}$ is the time for which samples were taken in minutes, η is the efficiency of the filter, which takes into account the number of particles which pass through the filter and the number of particles absorbed in the filter itself.

This method is widely used, convenient, and simple.

Electric separators can also be used to precipitate certain types of radioactive dust. However, since the method for the use of an electric separator is rather complex, it is preferable to use the method of precipitating radioactive dust on membranous filters described above. When determining the concentration of those active aerosols which are easily precipitated by solutions of acids, alkalis, and a number of other chemical reagents, it is convenient to use the liquid filter method.

Measurement of Radioactive Gases. End-window counters are now used for the radiometry of β-active gases. These devices consist of an easily compressible, airtight cylindrical chamber. The ends of the chamber are fabricated in such fashion that they are rigid, so that a counter and filter may be mounted centered in the ends. The samples are taken when the sampler opens as a result of the weight of the sample; in this case, the air passes into the chamber only through the filter and is cleansed of aerosols. The activity of the gas is measured in the sampler itself, in an area with a minimal background.

This method makes it possible to measure concentrations of β-active gases of approximately $5 \cdot 10^{-11}$ curies/l for argon (Ar^{41}), krypton (Kr^{85}), and xenon (Xe^{133}).

The use of an ionization chamber with "air walls" is to be recommended when it is necessary to determine the concentration of low-energy

β-active gases (when the mean free path of a β-particle in air is approximately 1 m). An "air" chamber consists of inner and outer electrodes fabricated from thin metallic grids (Al, Fe). The construction of this chamber makes it possible to reduce the effects of external γ-radiation by decreasing the secondary electron yield. This ionization chamber is used in conjunction with the "Cactus" radiometer. During measurements, the ionization chamber should be surrounded by a layer of contaminated air with a thickness no less than the maximum free β-particle path in air.

A self-recording instrument of the "Cactus" type can be used for monitoring waste gases. The five-liter chamber used for this purpose operates on a continuous-flow system.

The rate at which air is pumped through the chamber is kept constant, at ~20 l/min. A filter of a FP fabric is installed before the chamber in order to trap the radioactive aerosols. The specific activity of the gas (in curies/l) is determined from the scale of the "Cactus" radiometer, which is calibrated for a standard chamber. Self-recording of the activity furnishes an automatic signalling system which operates when the activity exceeds a predetermined level.

Two methods are used for monitoring contamination of the air with radon and thoron; the first involves continuous pumping of air through the measuring instrument and the second consists in withdrawing the air samples into an emanation chamber and subsequent exposure.

The first method is suitable for measuring the concentrations of radon and thoron; in this case, the SG-1M electrometer is used with an emanation chamber. The second method is used only for measuring radon; both the SG-1M electrometer and the SG-11M field emanometer, which has a measurement range extending from 10^{-11} to 10^{-6} curies/l, may be used for this purpose.

Chapter 2

MEDICAL MONITORING

Medical examinations, first introduced in the USSR in 1925, are now the most important curative and prophylactic measure in the prevention of occupational diseases. They permit correct selection of personnel to work with radioactive substances, simultaneously reveal the earliest symptoms of occupational disease in such personnel, and also indicate the presence of diseases of a general nature.

In order to elucidate the effects of radioactive substances which have entered the organism or are sources of external irradiation, it is necessary to take into account the characteristics of their biological and pathogenic effects.

The early symptoms of radiation sickness can be detected only by constant and systematic observation by a qualified physician and the use of various clinical and physiological research methods. In order to accomplish this, all therapeutic and prophylactic institutions which attend to enterprises and laboratories in which work with radioactive substances is performed conduct preliminary and periodic medical examinations.

The basic tasks of preliminary medical examinations for those entering work of this type are determination of the general state of health of the individual and detection of changes which may be counterindications for work with radioactive substances and sources of ionizing radiations.

A list of counterindications which may serve as a guide in medical

examinations is given in the Public Health Regulations for Work with Radioactive Substances and Sources of Ionizing Radiations No. 333-60.

The material gathered during preliminary medical examinations serves as the initial data for evaluating subsequent changes in the worker's state of health. Correct evaluation of the data obtained is an important criterion in the detection of the early symptoms of radiation sickness during periodic medical examinations.

The aid of physicians with specialties such as therapeutics, neuropathology, and gynecology is enlisted in conducting preliminary medical examinations. An opthalmologist must also participate in the examination when a worker is being admitted to work with high-power sources of ionizing radiation (in radiography or when radium and polynium or beryllium sources are involved), accelerators, and reactors. In certain cases, an otolaryngologist, an oral surgeon, or a dermatologist are consulted.

During the preliminary examination, a clinical analysis of the blood (hemoglobin, erythrocytes, leucocytes, composition, sedimentation rate, reticulocytes), a general urinalysis, an x-ray examination of the thoracic organs, and a symptomatic examination of other organs and systems (electrocardiogram, x-rays, a biochemical study of the blood or urine, etc.) are made. The findings of the examination determine the suitability of the individual for work at a certain task.

Periodic medical examinations have as their object dynamic observation of the workers' state of health, detection of the earliest functional changes and symptoms characteristic of chronic occupational disease, and opportune application of the necessary curative and prophylactic measures. In addition, these examinations make it possible to detect illnesses of a nonoccupational nature and to begin treating them at an opportune time.

After the medical examination is completed, the data obtained is analyzed, taking into consideration the sanitary and hygienic characteristics of the working conditions to be encountered (the concentration of radioactive and toxic substances in the air of the production areas, the degree to which equipment, clothing, and the hands are contaminated, dosimetric data on those examined, etc.). The material obtained makes it possible to decide whether the worker should be permitted to continue under certain conditions, to check the effectiveness of the curative and prophylactic measures taken, and to formulate new measures for improving sanitary conditions. All of the data must be entered in the medical record books which are kept for each person examined.

Periodic medical examinations of workers in various categories are conducted at varying intervals, the length of these intervals being determined by a number of factors: the quantity of radioactive substances at the work site, the activity and relative radiotoxicity of the isotope, whether the source is shielded or unshielded, the nature of the work performed, etc.

Berns has shown that, in cases where exposure to radioactive substances is limited to a small percentage of the maximum permissible exposure, periodic medical examinations need be made only two or three times a year. In cases where the danger of exposure is great or new materials, whose toxicity is unknown, are being used, examinations must be conducted monthly and even weekly in certain cases. In Berns' opinion, all workers who deal with radioactive substances must be examined no less frequently than once a year. Stoun also holds this opinion. In the Soviet Union, the intervals between medical examinations of workers who deal with penetrating radiation and unshielded radioactive substances have been established at three, six, or twelve months.

The degree to which specialists participate in these periodic medical examinations is determined by the radioactive substance or source of ionizing radiation with which the worker has come into contact. However, it is obligatory that specialists in therapeutics, neuropathology, and gynecology participate in the examinations in all cases.

An opthalmologist is also consulted when the work involves high-power sources of external radiation or is performed at accelerator or reactor installations. In certain cases, the worker is also examined by a dermatologist, an otolaryngologist, or an oral surgeon. The findings of the examination are used as the basis for roentgenoscopy and roentgenography of individual organs. However, it is necessary to limit x-ray studies in order to reduce the additional exposure, since the dose received during a single session of fluoroscopy and x-raying can greatly exceed the worker's maximum permissible yearly dose.

A clinical analysis of the blood is made during each periodic medical examination. If any doubt arises as to the reliability of the data yielded by these analyses or if there is a deviation from the original indices, the analyses are repeated without waiting for the next examination.

Analyses of the urine, feces, gastric contents, duodenal contents, sputum, nasal mucus, etc. are of substantial importance in the detection of early functional changes in individual organs and systems.

Biochemical studies of the urine are of great importance in evaluating damage to the liver and kidneys and are made when the urine contains bile pigments, urobilin, etc. When there is a possibility that gaseous radioactive aerosols may be inhaled, the activity of the exhaled air is investigated. The intervals at which biological environments are investigated depend on the worker's state of health, the

working conditions, etc.

After the periodic medical examination, the worker's state of health is evaluated and an indication is given of the feasibility of his continuing at his former work.

Various curative and prophylactic measures, which depend on the extent of the disruptions detected in the state of the worker's health and the stability of these disruptions, are provided for; these measures include outpatient observation, dietetic food, admission to a prophylactic clinic, rest home, sanitorium, or hospital, leave of absence, temporary or permanent separation from duty, etc.

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